



GODFREY LOWELL CABOT SCIENCE LIBRARY
of the Harvard College Library

This book is
FRAGILE
and circulates only with permission.
Please handle with care
and consult a staff member
before photocopying.

Thanks for your help in preserving
Harvard's library collections.



o/ Eng 5057.64

HARVARD CO



BOUGHT FROM THE
BEQUE/
PETER PAUL FI
OF 1

FOR FRENCH WORKS AND PERI
AND ON CHEMISTRY, ASTR
APPLIED TO THE AR

THE
ELEMENTS
OF
NAVAL ARCHITECTURE:
OR, A
PRACTICAL TREATISE
ON
SHIP-BUILDING.

By M. DUHAMEL du MONCEAU,
Inspector General of the Marine to his Most Christian Majesty, Member of the Royal Academy of Sciences at Paris, and Fellow of the Royal Society at London.

CAREFULLY ABRIDGED
By MUNGO MURRAY.

LONDON:
Printed for A. MILLAR, in the Strand.
MDCCXLIV.

Eng 50.57.54



De grand fond

CONTENTS.

	Pages.
<u>CHAP. I.</u>	
G eneral Proportions for Building	1
<u>CHAP. II.</u>	
Of the Scantlings and Dimensions of the principal Pieces of Timber in a Ship	10
<u>CHAP. III.</u>	
A method to lay down a 70 Gun Ship upon the Plane of Elevation	15
<u>CHAP. IV.</u>	
To lay down the Frame upon the Plane of Projection	21
<u>CHAP. V.</u>	
Of the Projections on the horizontal Planes, and of the Water and Ribband Lines on the Plane of Elevation, and that of the Projection	33
<u>CHAP. VI.</u>	
Another Method of laying down the Horizontal Plane, and the Plane of Projection	39
<u>CHAP. VII.</u>	
General Remarks on Ship Building	46
<u>CHAP. VIII.</u>	
To know by the Draught how high a Ship will carry her Guns out of the Water	49
<u>CHAP. IX.</u>	
A Method to calculate the Resistance of the Water upon the fore Part of the Ship	57

A

PRACTICAL TREATISE

O N

S H I P - B U I L D I N G.

C H A P. I.

General Proportions for Building.

NAVAL Architecture may be divided into three principal parts.

I. To give the ship such a figure, or exterior form, as may suit the service she is designed for.

II. To find the true form of all the pieces of timber that shall be necessary to compose such a solid.

III. To make proper accommodations for guns, ammunition, provisions, and apartments for all the officers, and likewise for the cargo.

We shall at present only treat of the first of these, namely the exterior figure, and consider it first, as it regards the bottom, that is, the part which lies under water, and may be called the quick-work; or, secondly, the part which is above water, and may be called the dead-work.

In order to give a proper figure to the bottom, all the qualities which are necessary to make a ship answer the service for which she is designed, should be considered. A ship of war should carry her lower tier of guns four or five feet out of the water. A ship for the merchants service should stow the cargo well, and both of them should be made to go well, carry a good sail, steer well, and lie to easily in the sea.

B

Some

Some eminent geometricians have endeavoured to find the form of a solid which may best answer all these qualities, and meet with the least resistance in dividing the fluid through which it is to pass; but have not been able to reduce their theory to practice, by reason of the different positions a ship is obliged to be in when under sail. The ship-builders, despairing to establish this point by mathematical rules, have applied themselves wholly to their own observations and experience, which may indeed supply the deficiencies of art; but though they may thereby discover that a ship has several bad qualities, it will not be easy to determine where the fault lies; for it may be owing to the rigging; and though the fault be not there, yet they cannot be certain in what particular part of the body it is. If their observations be assisted by principles drawn from theory, it will conduce very much to attain their end.

As there have been several ships built which have seemed to answer all the services for which they have been designed, some builders have made it their principal study to copy ships which have gained the applause of the seamen. This method they very improperly call the principal rule which should be observed in building. Now, as the bodies of ships are very different from one another, so there are, by this means, as many different methods used; some chusing one, and some another for a standard. But it must be observed, that even though it were possible to find such a body as should give entire satisfaction, and have all the good qualities that should be necessary to answer the services proposed, yet this could by no means be established as a standard by which other ships of different dimensions may be built. For admitting we have a first rate of 100 guns, which by experience has been found to be a very good ship in all respects, yet we should find ourselves very much deceived, if we should build a ship of 20 guns by making all the parts have the same proportion to one another, that they have in that of 100 guns.

The first thing to be done, in order to lay down the draught of a ship, is to determine the length, which should be either on the lower gun deck, or at the load-water line; for there must be great care taken that there is a sufficient space betwixt the ports. This will oblige us first to fix the number and dimensions of the ports, the distance of the aftermost port from the transom, and of the foremost from the stem, and the distance betwixt the ports. This article may be determined by the following tables:

A Table

A Table of the Number of Ports on each Side of a Ship, according to the Number of Guns, and the Weight of the Shot.

A Ship of 112 Guns.			A Ship of 102 Guns.			A Ship of 74 Guns.		
Decks	Ports	Shot	Decks	Ports	Shot	Decks	Ports	Shot
1	15	48 or 36	1	14	36	1	13	36
2	16	24	2	15	18		14	
3	15	12	3	14	12	2	14	18
Quarter	5	8	Quarter Forecastle Poop	13	6	Quarter	15	
Forecastle	3	8				Forecastle	8	8
Poop	2	4				Poop	8	4
A Ship of 64 Guns.			A Ship of 58 Guns.			The Tiger.		
Decks	Ports	Shot	Decks	Ports	Shot	Decks	Ports	Shot
1	12	24	1	12	18	1	11	18
	13		2	13	12	2	12	8
2	13	12	Quarter Forecastle	4	4	Quarter	3	6
	14					Forecastle	2	4
Quarter	7	6						
Forecastle	5							
A Ship of 50 Guns.			A Frigate of 46 Guns.			A Frigate of 32 Guns.		
Decks	Ports	Shot	Decks	Ports	Shot	Decks	Ports	Shot
1	11	18	1	11	12	1	10	6
2	12	12	2	12	8	Quarter Forecastle	6	4
Quarter	2	4						
A Frigate of 32 Guns.			A Frigate of 32 Guns.			A Frigate of 28 Guns.		
Decks	Ports	Shot	Decks	Ports	Shot	Decks	Ports	Shot
1	4	8	1	10	8	1	3	8
2	10	6	2	6	6	2	10	4
Quarter	2	4				Quarter	1	4
Forecastle								
A Frigate of 24 Guns.			A Frigate of 22 Guns.			Frigates of 20 Guns have		
Decks	Ports	Shot	Decks	Ports	Shot	10 Ports on each side		
1	10	6	1	9	6	on one Deck. Shot 6 lb.		
Quarter	2	4	Quarter	2	4			

Vessels of 16 guns have 8 ports on one deck, the guns to carry 4 lb. shot.

Vessels of 12 guns have 6 ports on one deck, the guns to carry 4 lb. shot.

A Table of the Dimensions of the Ports, and Height of their Sells, according to the Weight of the Shot.

Shot	Hei. and brea. of ports				Height of the ports				Sells	
lb.	f.	in.	l.	f.	in.	1st Deck	2d Deck	3d Deck	Quarter-Deck and Forecastle	
48	2	9	3	0	or 3	2	f. in.	f. in.		
36	2	8	3	0	or 3	1	2	2		
24	2	5	2	8	or 2	10	2	1	2	0
18	2	4	2	7	or 2	8	1	11	1	9
12	2	2	2	4	or 2	6	1	10	1	8
8	1	9	1	11	or 2	3	1	8	1	6
6	1	6	1	8	or 1	11	1	7	1	6
4	1	4	1	6	or 1	9	1	5		

A Table of the Number, Dimensions and Distances betwixt the Ports on the lower Deck; also the Distance betwixt the foremost Port and the Stem, betwixt the Aftmoft and the Sternpost.

Ships Names.	N ^o of Breadth		Dist. betw. Ports	Foremoft from Stem	Aftmoft from Post	Length on L. Deck
	Ports	of Ports				
Amiable	13	2 8	7 6	13 4	9 0	147
Invincible	13	2 8	7 4	12 4	9 0	144
Achilles	12	2 8	7 8	18 2	10 6	145
Toulouse	12	2 8	7 6	17 4.	9. 2	141
Ardent, 64 guns	12	2 8	7 6	17 0	9 2	140 8
Fleurion, 64 guns	12	2 8	7 8	18 10	10 6	145 8
Dauphin Royal, 74 guns	13	2 10	7 7	18 2	10 0	156

Note. An inch *French* measure is equal to $1 \frac{1}{10}$ inch *English*, and is divided into twelve parts called lines, which are divided into twelve parts, called points.

The next thing to be done is to establish the breadth by the midship-beam; the builders are pretty much divided in proportioning this to the length. Most of them conform to dimensions taken from ships of the same burthen, and designed for the same service.

After these two dimensions are determined, the depth of the hold must be fixed, which in most ships is half the breadth; but the form of the body should be considered; for a flat floor will require less hold than a sharp one. The distances likewise between the decks must be determined. The following table may be very useful towards ascertaining the three aforesaid dimensions.

A Table

A Table of the Length, Breadth, and Depth in Hold of the following Ships.

Ship's Names	Guns	Length at load-water line		Breadth		Depth in the Hold	
		feet	in.	f.	in.	f.	in.
Monarque	74	165		43		20	6
Intrepide	74	165		43		20	6
Alcide	64	149		40	6	19	4
Renommée	30	120		31	8	15	7
Palme	12	85		22	6	10	5
Soleil Royal	80	182		48		23	
Formidable	80	178		44	10	21	10
Tonnant	80	168		46		23	
Sceptre	74	165		43		20	6
Superbe	74	153	6	42	8	21	
Esperance	74	154		42		21	
Magnifique	74	165		43		20	6
Northumberland	68	149		40		20	
Lis	64	149		40		19	
Hercule	64	149		40	6	19	4
Protee	64	150		40	6	19	4
Illustre	64	150		40	8	20	
Opinatre	64	150		40	4	19	5
Dragon	64	149		40		19	
Leopard	64	146		39	6	18	6
St Laurent	60	145		39	4	18	8
Amphion	50	145		39		18	
Amazon	44	118		35		17	
Brillant	50	135		35		17	9
Arc-en-Ciel	50	135		37		17	
Tigre	52	131		37		17	
Alcion	50	132		35	4	18	
Aquilon	46	127		34		17	
Junon	46	136		36	6	16	6
Favorite	36	127		33		14	
Anglesea	32	121	8	33	6	16	
Serenne	30	118		31	8	15	9
Emeraude	28	118		31	8	16	
Galatée	24	110		29		14	6
Mutine	24	110		29		14	6
Cumberland	24	102		26		13	
Marshall Saxe	22	100		27		14	
Anemone	12	84		22		9	

Ship's Names	Guns	Length	Breadth	Depth
		feet	f. in.	f. in.
Amarante	12	84	22	9
Elizabeth	64	143	38 4	18
Brave	80	172	44	21
Florissant	74	165	45	22 6
Couronne	74	167	44	22 7
Hardi	64	149	40 6	20 9
Aigle	50	144	39	19 6
Hermione	26	126	33 8	13 8
Juste	70	151	42	21
Triponne	26	114	31 8	
Panthere	20	108	28 6	
Badine	6	66	18 4	

We may then proceed to fix the length of the keel, which will oblige us to determine the rake of the stem and post, for which the builders have given us no invariable rule, they being very much divided in their opinions; for where some have given a rake of 18 or 20 feet, others have given none at all. The height of the stem and wing-transom must also be determined, which may be regulated by the decks.

The difference betwixt the draught of water abaft and that afore, should likewise be considered; for though some imagine that when a ship is loaded her keel should be parallel to the surface of the water, yet in many cases it will be found necessary that the keel abaft should be deeper in the water than it is afore. This will give the rudder more power, and thereby contribute to make a ship steer well; but this difference of the draught of water is intirely arbitrary; for in large ships some have given five, whereas others have given but three, or even two feet of difference. Though I could not procure the true difference of the draught of water of many ships of war, yet I am assured that the following are pretty exact.

The Difference of the Draught of Water in the following Ships.

	feet	in.		feet	in.
Northumberland	1	2	Panthere	1	4
Auguste	1	6	Couronne	2	1
Aloze	1	0	Triponne	2	
Hermione	2	0	Renommée	1	4
Amazon	1	6	Tigre	3	2
Badine	0	10	Intrepide	2	3
Palme	1	4	Alcide	2	0

The

The length of the wing transom must also be determined; some make it $\frac{7}{8}$ of the main breadth; but this is likewise arbitrary, the broader a ship is abaft, the more room there will be for accommodations for the officers; but this will be disadvantageous to her sailing upon a wind.

The following Examples will be sufficient to fix the Length of the Wing transom for any Ship.

For a ship of 110 guns, $\frac{3}{4}$ of the main breadth, and 3 lines more to every foot.
 102 guns, $\frac{7}{8}$ of the main breadth, and 8 inches more.
 82 guns, $\frac{3}{4}$ of ditto.
 74 guns, 7 inches, 9 lines for every foot in breadth.
 62 guns, 7 inches, 8 lines for ditto.
 56 guns, 7 inches, 7 lines, 3 points for ditto.
 50 guns, 7 inches, 6 lines, 6 points for ditto.
 46 guns, 7 inches, 6 lines for ditto.
 32 guns, 7 inches, $5\frac{1}{2}$ lines for ditto.
 For a frigate of 22 guns, 7 inches 4 lines.
 12 guns, 7 inches.

Some, without regarding these proportions, make the wing transoms of the first and second rates two thirds of the breadth, and for all the rest one foot less.

After these dimensions are determined, the timbers may be considered which form the sides of the ship. A frame of timbers is composed of one floor timber, two or three futtocks and a top timber on each side: All these being united together, and secured by cross-bars, form a circular inclosure, that which incloses the greatest space is called the midship frame: The curve of this frame is inverted at the lower part, so that the floor timber will be somewhat hollow in the middle, whereby the ends will form a very obtuse angle; but this angle decreases the farther the frames are removed from the midships, in such a manner, that the foremost and aftermost will become very sharp, and form a very acute angle. These floor timbers are called crutches.

The builders seem to agree nearly as to the length of the midship floor timber, making it generally half the length of the main beam; but they differ very much about the rising of it, some chusing a flat and others a sharp floor. And if we consider the advantages and disadvantages that attend the one and the other, we shall not be much surprized to find them so much divided upon this article; for it is certain, the more rising a ship has, she will hold the better wind, but then this will occasion her to draw more water, which will be sometimes attended with very great inconveniences.

A Table

A Table of the rising of the Midship Floor Timbers.

Guns	f.	in.	lines.		Guns	f.	in.	lines	
710	0	0	10	} to every foot in length.	56	0	1	4	} to every foot in length.
102	0	0	10 $\frac{1}{2}$		32	0	1	4	
86	0	1	0		28	0	1	4	
74	0	1	0		22	0	1	6	
62	0	1	0 $\frac{1}{2}$		16	0	1	6	

Note, *What we have here rendered the rising of the floor timbers, the author calls the Aculement, and makes a distinction betwixt it and the rising, which we shall see when we come to form the frames.*

They differ as much in determining the station of the midship frame, some placing it before, others at the middle of the ship; others again have two floor timbers of equal length, and rising, one of which is placed exactly in the middle, or the breadth of the timber before the middle, and the other at a proper distance before it. Those who place it before, alledge, that if a ship is full forward, after she has once opened a column of water, she will afterwards meet with no resistance, and the water will easily unite abaft, and by that means force the ship a-head, and have more power on the rudder the farther it is from the centre of gravity; and besides this comes nearest the form of fishes, which should seem to be the most advantageous for dividing fluids.

Those who would have it placed in midships say, that by that means the water-lines forward will be easier, and of consequence properer for dividing fluids; and that there will be space enough betwixt it and the rudder for forming very fair water-lines, so that the water will easily unite at the rudder; and besides it will be easier by this means to balance the fore body and after body; and in general the building will by this means be very much facilitated; so that, in my opinion, it will be properest to place it very near the middle, though it is the general practice to place it before it.

After the rising of the midship floor timber is determined, we may then proceed to fix the height of the rising line of the floor abaft on the post, and afore upon the stem.

Now, as all ships are narrower abaft and afore, than in midships, the other floor timbers will of consequence be shorter and have a greater rising, which will be still increasing till it ends on the post and stem. There are several different methods used by the builders to settle the height of this line. Some imagine, that by narrowing the floor abaft, which will occasion the rising line to be high upon the post, the ship will

will thereby steer better, and besides, the water which is opened by the midship frame will then have a greater pressure upon the after part of the ship, and thereby contribute to her sailing: Yet these arguments are of very little weight; for if we only consider the steerage, it is certain, that the higher the rising line is carried abaft, and the narrower a ship is, the water will have the easier passage, and more power upon the rudder. But then we shall thereby run the risk of falling into two great inconveniencies; for, by this means, we take away the buttock, which is the only thing we have to support all the weight of the after part of the ship; neither shall we be able to give a proper balance betwixt the fore and after part; and when the fore and after parts are not duly balanced, it will occasion a ship to pitch very hard, and be in danger of being frequently pooped by the sea when it runs high. To prevent these inconveniencies, it will be proper to give all ships, especially the large sort, a full buttock. As to the height of the rising line afore, it should be determined by the form of the water lines; but before this can be done, the timbers must be formed.

Note, What we have rendered the rising line of the floor, our author calls les façons, which, he says, is the increase of the acculement, the extreme points of which upon the perpendicular of the stem and post are now to be determined.

The height of the lower deck is the next thing to be considered: It is determined in midships by the depth of the hold, and some builders make it no higher at the stem; but they raise it abaft more than it is in midships, as much as the load-water mark abaft exceeds that afore. As to the height betwixt decks, it is altogether arbitrary, and must be determined by the rate of the ship, and the service that she is designed for.

We come now to consider the upper works, or all that is above water, called the dead-work: And here the ship must be narrower, so that all the weight that lies above the load-water line will thereby be brought nearer the middle of the ship; by which means she will strain less by working the guns, and the main sail will be easier trimmed when the shrouds do not spread so much. But though these advantages are gained by narrowing a ship above water, great care must be taken not to narrow her too much, for there must be sufficient room upon the upper deck for the guns to recoil. The security of the masts should likewise be considered, which requires sufficient breadth to spread the shrouds, though this may be assisted by enlarging the breadth of the channels.

C H A P. II.

Of the Scantlings and Dimensions of the principal Pieces of Timber in a Ship.

ALTHOUGH it is not my intention, as I observed in the beginning of the last chapter, to treat of all the pieces that compose the ship, yet I think it necessary to say something of the principal pieces. I shall therefore, in the following plate, lay down each piece by itself, by which means we shall see the length of the scarphs, and in what manner they are to be joined together.

Explanation of Plate I.

I.

A. The keel in four pieces, to be well bolted together, and clinched.

II.

I. The fore foot, one end of which is scarphed to the fore end of the keel, of which it is a part, and the other end makes a part of the stem, to which it is scarphed.

III.

u u. Two pieces of dead wood, one afore and the other abaft, fayed upon the keel.

IV.

C C. The stem in two pieces, to be scarphed together.

V.

E E. The apron in two pieces, to be scarphed together, and fayed on the inside of the stem, to support the scarph of the stem; for which purpose the scarph of the apron must be clear from that of the stem.

VI.

a. The stemson in two pieces, to support the scarph of the apron.

a. The false post, which is fayed to the fore part of the post.

VII.

B. The stern post: It is tenanted into the keel, to which it is fastened with a knee.

D. The

VIII.

D. The back of the post, which is likewise tenanted into the keel and well bolted to the post; the design of it is to give sufficient breadth to the post, which seldom can be got broad enough in one piece.

IX.

F. The knee which fasteneth the post to the keel.

X.

N. The wing transom. It is fayed across the stern post, and bolted to the head of it: The fashion pieces are fastened to the ends of it; underneath this and parallel to it is the deck transom.

XI.

O O. Two transoms fastened to the stern post and fashion pieces, in the same manner as the wing transom.

XII.

P. The transom knee, which fasteneth it to the ship's side.

XIII.

Q. The fashion piece, of which there is one on each side: Their heels are fastened to the stern post at the height of the floor ribbands, and their heads are fastened to the wing transom.

XIV.

T. A floor timber. It is laid across the keel, to which it is fastened by a bolt through the middle.

XV.

K. The lower Futtock.

XVI.

T T T T T. 2d, 3d, 4th futtocks and top timbers. These shew the proper length and scarph of the timbers in midships frame.

XVII.

U U. Riders. These are fayed in the inside of the ship, and consist of floor and futtock riders.

C 2

Z. The

XVIII.

Z. The keelson. This is made of two or three large pieces of timber scarphed together in the same manner as the keel. It is placed over the middle of the floor timbers, and scored about an inch and an half down upon each of them.

XIX.

R S. Breast-hooks. These are fayed in the inside to the stem, and to the bow on each side of it, to which they are fastened with proper belts. There are geneally four or five in the form of R in the hold, one in the form of S into which the lower deck planks are rabbited; there is one right under the hawse holes, and another under the second deck.

XX.

X, Y, Z. are thick planks which are fayed in the inside, and stretch fore and aft to strengthen the scarphings of the timbers.

XXI.

Z. are thick planks in the inside, called clamps, which support the ends of the beams.

XXII.

15, 15, 15, 15, 15, are the wales. They are planks broader and thicker than the rest, which are fastened to the outside of the ship in the wake of the decks. We shall have occasion in another place to show how they are laid down in a draught. As to the plank below the wale to the keel, and above it to the top of the side, we refer to the section of one half of the midship frame, as laid down in the plate.

XXIII.

d, d, d, d, d, d, are knees. These are crooked pieces of timber consisting of two arms, which form an angle, either within or without a square, or exactly square; their use is to fasten any two pieces together, as the beams to the ship sides.

XXIV.

19. The rudder. This is joined to the stern post by the rudder irons, upon which it turns round in the googings which are fastened upon the stern post for that purpose. There is a mortise cut out of the head of it,

it, into which a long bar is fitted, called the tiller, by which the rudder is turned from one side to the other.

XXV.

23. The cat heads. These are two large pieces of square timber, one on each side of the bowsprit. They project out before the bow, in order to keep the anchor clear of the ship, which is hove up by a rope called the cat fall, that passes through shivers in the outer end of the cat-head: Their inner ends are fastened upon the forecastle.

XXVI.

m, m, i, i, are the several pieces which compose the knee of the head; the lower part *m* is fayed to the stem, the heel of it is scarphed to the head of the forefoot; it is fastened to the bows by two knees called checks, in the form of *f*, and to the stem by a knee called a standard, in the form of *K*.

XXVII.

Beams &c, *a, X Y*, are large pieces of timber which support the planks of each deck.

Having thus explained all the pieces in the plate, we shall in the following table give their scantlings.

SCATTLINGS of the principal Pieces of Timber in a SHIP

[illegible]

Note. The Scandalings of the Knees moulded is $\frac{2}{3}$ from the Throat.

1

2

3

4

5

6

7



C H A P. III.

A Method to lay down a Seventy Gun Ship upon the Plane of Elevation.

THE Dimensions we have given of the principal parts of a ship of each class collected from the practice of different builders, which many have so great a regard to, as not to vary from them in the minutest article, we think only to be so far observed, as they shall produce such a form as the service the ship is designed for, shall require, agreeable to mathematical principles.

We shall now illustrate what has been said on that head by drawing a ship from these dimensions. But it will be first necessary to observe, that the builders make use of three different planes for one ship; 1st, the plane of elevation, in which the whole length is laid down according to a side view; 2d, The plane of the projection, which some call a vertical plane of the timbers, because it gives us an end view of the form of all the timbers, before the plank is put on. 3d, The horizontal plane, upon which are described all the curves that are formed by sections of the body parallel to the horizon, which must be considered as well as those vertical sections which form the curves of the timbers. We may likewise form the curves of the ribbands upon this plane, which will be of great use in proving whether the form we give the timbers will produce a fair side.

It is indifferent with which of these we begin, though that of the elevation seems most commodious. But first of all it will be very proper to draw out a list of all the dimensions of the vessel we are to build, so that we may have a view of the whole design.

This ship then is to have two tier of guns, so there must be two decks quite fore and aft, likewise a quarter deck as far as the main mast, a fore-castle 33 feet long, and a poop to the mizen mast.

There are to be 13 ports of a side on the lower deck, the guns to carry 24 lb shot; 14 ports on each side upon the upper deck, the guns to carry 18 lb shot; on the quarter deck 4 guns, and on the fore-castle 2 guns of 8 lb shot on each side, and 2 of 4 lb on each side on the poop.

Ports

	feet	in.	l.
Ports on the lower deck fore and aft	2	10	
Distance betwixt the ports	7	9	
Aftermost port from the post	9	3	
Foremost from the stem	17	2	
Height of the fells, including the lower deck planks	2	5	
Ports up and down on the lower deck	2	7	
Distance from the upper side of the lower deck beam to the upper side of the upper deck beams	6	11	
Rising of the second deck abaft		11	
Second deck ports up and down	2	4	
Second deck ports fore and aft	2	6	
Height of the fells from the deck line	1	11	6
Distance betwixt the second deck and quarter deck from plank to plank	6	6	
Quarter deck ports up and down	1	10	
Quarter deck ports fore and aft	2		
Height of the fells	1	4	
Distance betwixt the quarter deck and poop	6	2	
Ports on the poop fore and aft	1	10	
Height of the fells	1	0	
Length from rabbit to rabbit on the gun deck	156	3	
Extreme breadth	42		
Depth in the hold below the plank	21	0	0
Rising of the lower deck abaft, not including the difference of the draught of water	2	11	6
Height of the stem	31	9	3
Height of the post	31	7	9
Rake of the stem	15	7	2
Rake of the post	3	1	5
Length by the keel	139	6	10
Depth of the keel	1	7	3
Length of the wing transom	27		
Length of the midship floor timber	21		
Rising of ditto	1	9	
Difference of the draught of water abaft more than afore	3	2	
Height of the rising line of the floor abaft	13	6	0
Height of the rising line of the floor afore	5	7	5

I would advise young beginners in the art of drawing to conform exactly to these dimensions, which we have here given for an example, and

and observe all the particular directions which we shall give in laying down a ship of 70 guns; for they must begin by making themselves acquainted with the terms, and thereby gain a general idea of the whole design. After finishing this draught, they may then proceed to another of a different rate, and as we have given the principal dimensions of several good ships, they may chuse such a one as will best answer their design.

Plate II. Fig. I.] 1st. Provide a scale of equal parts properly divided into feet and inches, adapted to the intended length of the draught, and draw the line A B, which make 156 feet 3 inches for the length of the gun deck, from the rabbet of the stem to that of the post.

To find the length on the gun deck, multiply 13, the } f. in. 1.
number of ports, by 2 f. 10 in. the dimensions of each port } 36 10 0
fore and aft, the product is

Again multiply 7 f. 9 in. the distance betwixt the ports, by } 93 0 0
12, the number of spaces, the product is

Aftmost port before the post	9 3 0
Foremost abaft the stem.	17 2 0
Length on the gun deck	156 3 0

2dly, Draw the line C D equal and parallel to A B, let 21 feet, the half of the main breadth, be the distance betwixt them, and erect the perpendiculars C F and D Z.

3dly, Set off 3 feet 2 inches, the difference of the draught of water, from B to G, and draw the line A G, which will give the position of the lower side of the keel. From A set off 1 foot 7 inches 3 lines, the depth of the keel, as in the table of scantlings, to K, and draw the line K I parallel to A G, which will be the upper side of the keel.

4thly, Set off 1 foot 3 inches 3 lines, the breadth of the stem, from G to M, and draw the dotted line M N parallel to G Z. From G set off 15 feet 7 inches 2 lines, the rake of the stem, to O.

5thly, Set up 31 feet 9 inches 3 lines, the height of the stem from G to P. With the radius I P describe the arch P O, which will be the fore side of the stem, and from the same center describe another arch within the former, which will give the inside of the stem, and another arch for the rabbet may be described four inches before the inside of the stem.

6thly, Set up 25 feet 1 inch from K to L for the height of the gun deck abaft, and 21 feet 6 inches from I to e, for the height afore.

7thly, Set up 2 feet 5 inches, the height of the port-bells from L to a, which will give the upper side of the wing transom; from which set up
D. 2 feet:

2 feet 7 inches, the height of the ports; also 1 foot for the depth, and 6 inches 9 lines for the round of the helm port transom, to the point F, which will be the height of the post; so K F will be 31 feet 7 inches 9 lines. From K set off 3 feet 1 inch 5 lines to *f*, for the rake of the post, and draw the line F *f* for the aft side of the post. From *f* to *b* set off the depth of the keel, and draw the line *b d* for the fore side of the post, making F *d* $\frac{1}{2}$ of *f b*, so shall *f O* be the whole length of the keel.

The builders are very much divided about assigning a proper place for the midship frame, for which the following method may be used.

Divide the line C D into two equal parts, then take 5 feet 6 inches 10 lines, that is $\frac{1}{11}$ part of 156 feet 3 inches, the length of the gun deck: Set off this before the middle of the line C D, which will give the point F, the station of the midship frame. Set up 21 feet from F to Z, which will give the height of the gun deck at the midship frame. From the point Z set off 2 feet 7 inches 6 lines (the $\frac{1}{4}$ of the height of the gun deck at the midship frame,) through which point draw a line V T, parallel to C D, which will be the load-water line. Through the point F draw the line G g, parallel and equal to the load-water line, which will shew how much water the ship will draw abaft more than afore.

One of the frames is placed pretty near the cheffs tree, which is called the loof frame; to find its place, from the point D set off $\frac{1}{4}$ of the line D C, and there draw a dotted line perpendicular to A B. Again divide the line F G into nine equal parts, and draw eight lines perpendicular to A B, which will station eight frames in the fore-body besides that of the loof.

There is in the after-body a frame to balance that of the loof in the fore-body; these two are of equal breadth in some points, and this will occasion the center of gravity of that part contained betwixt these two frames to be near the plane of the midship frame, which will keep the fore part and after part upon a balance. It must be as far abaft the middle of the line C D as that of the loof is before it.

The frames in the after-body are the same distance from one another as they are in the fore, which will occasion one more abaft than before; so there are nine abaft, besides that of the balance.

We shall in the next place lay down the deck lines, and first for the lower deck draw a fair curve through the points L Z e, and parallel to it draw another curve for the port-sells, which are 2 feet 5 inches above the deck line.

The

The aftermoſt port is 9 feet 3 inches before the poſt, which ſet off to n , and the ports are 2 feet 10 inches fore and aft; which ſet off from u to x , the diſtance betwixt the ports is 7 feet 9 inches, which ſet off from x to Y for the aft ſide of the ſecond port; from Y again ſet off 2 feet 10 inches, which will give the foreſide of the next. Proceed in the ſame manner till all the ports are ſpaced; ſo ſhall the foremoſt port be 17 feet 2 inches abaft the rabbit of the ſtem. The height of the ports is 2 feet 7 inches, which ſet up from u ; draw a curve parallel to the deck line, which will give the upper part of all the ports; after which theſe two lines may be wiped off the draught, which muſt be therefore drawn with a black lead pencil, and only the ports inked in.

Draw a line for the upper deck, which is 6 feet 11 inches above the lower from the midſhip frame forward, and 6 inches more abaft. We may then draw a line for the port-bells, and one for their height, parallel to the deck line, and ſpace the ports ſo that they may be exactly over the middle of the diſtance betwixt the lower deck ports.

Before we can ſet off the height of the quarter deck we muſt find the true place of the main maſt. The general rule is to take 4 lines for every foot the gun-deck is in length, and ſet it off abaft the middle, which will give the foreſide of the maſt, now the length 156 feet 3 inches $\times$ 4 lines = 625 = 4 feet 4 inches 1 line, which ſet off abaft the middle of the line $C D$; and there erect a line perpendicular to the water-line, which will be the fore ſide of the maſt; and parallel to it draw a line for the middle, and one for the aft ſide of the maſt, the diameter of which is 35 inches. Set off 6 feet 6 inches on the aft ſide of the main maſt, for the height of the quarter deck afore, and 6 feet 10 inches for the height abaft; and draw a line nearly parallel to that of the upper deck, which will be the line for the quarter deck. We may then ſpace the ports, ſo that they may be exactly over thoſe of the lower deck. The forecaſtle is 6 feet 6 inches high, at which diſtance draw a line parallel to the upper deck line, which will give the line for the forecaſtle deck. As to the length of this deck, it ends forward at the beak head, and is carried aft diſcretionally, obſerving to leave room for the capſtan bars. In ſpacing the ports upon the forecaſtle, care muſt be taken that none be oppoſite to the fore maſt. Now to find the center of this maſt, take 15 feet 7 inches 2 lines, the tenth part of the whole length, which ſet off from the rabbit of the ſtem upon the lower deck abaft, from which point ſet off 32 inches and 1 line, being the diameter of the maſt; through the middle of this draw a perpendicular line, as in the plate. The boltſprit generally makes an angle of 34 or 35 degrees with the load-water line.

The poop is pretty near parallel to the quarter deck; the distance betwixt them forward is 6 feet, and abaft 6 feet 3 inches. It ends about 18 inches before the mizen mast, the aft side of which is $\frac{2}{7}$ of the main breadth before the rabbit of the post upon the gun deck.

The counter is generally an arch passing from the upper side of the wing-transom to the lower side of the beam of the second deck. The rake of the lower counter is $\frac{1}{4}$ of an inch for every foot of the main breadth. The rake of the second counter is $\frac{1}{4}$ of the lower; its height above the deck is 3 feet 5 inches. The hollow of the counters is altogether arbitrary, insomuch that some give none to the lower. The upright of the stern rakes 2 inches in a foot, as in the plate.

The beauty of a ship depends much upon giving the wales a proper hanging; for by them the sheer and drift rails are regulated, being all nearly parallel to one another, though they generally rise a little more abaft on account of the accommodations for the officers. It is this which makes a ship look airy and graceful in the water. There is no certain rule for laying them down; this is left entirely to the fancy and taste of the artist; but in placing the wales great care must be taken that they be wounded as little as possible by the ports; the foremost port on the gun deck must be $1\frac{1}{2}$ or 2 inches above, and the third port from abaft just touch the upper side of the upper strake of the main wales. The lower edge of the lower strake may glance with the edge of the water when loaded. There are two strakes of wales, and one strake between them of 15 inches broad each. The range of the deck should be considered in placing the wales, so that the scuppers may be in the strake betwixt the wales. The like caution must be used for the channel wales as may be seen in the plate, where they are all laid down, together with the sheer and drift rails; the rails, checks, and knee of the head are likewise laid down in the plate, and being for an ornament to the ship, are left to the fancy and taste of the builder. Though the knee may help a ship to hold a good wind, the fore part of it is generally one twelfth part of the length before the stem.

C H A P. IV.

To lay down the Frames upon the Plane of Projection.

HAVING thus explained all that is necessary to be delineated upon the plane of elevation, the next thing to be determined is the different breadths of the ship at any assigned points of the length, whereby we shall gain the forms of all the planes that are made by sections, perpendicular to the load-water line. The timbers that compose the body of a ship are supposed to have their planes in that position, and may be all delineated upon the plane of the projection; but as both sides of a ship are exactly the same, it will suffice to lay down the half of each, those of the fore-body on the right, and those of the after-body on the left hand. And whereas these planes diminish afore and aft, the planes of all the frames may be all delineated upon the plane of the midship one, which may be called the master-frame. The first thing then necessary to be known, is how to form this frame.

The mid-ship frame is that which is at the broadest part of the ship. The builders differ about the form of this frame, but there are several preliminary operations which are necessary to be observed in all the different methods used in forming it.

Preliminary Operations for forming the Midship Frame.

Plate III, Fig. I. and II.] 1st. Draw the line AB to represent the upper side of the keel; it must be at least as long as the ship is broad. This line our author calls the line of *aculement*, because upon it the aculement of the midship floor timber terminates.

2dly, Draw the line CD parallel and equal to AB, so that AC and BD may be equal to the rising of the midship floor timber. This line may be called the rising line, because it limits the height of the ends of the midship floor timber above the keel.

3dly, Draw the line GH, for the height of the lower deck, parallel to the former; and below this, draw a line to represent the load-water line, taking its distance below the deck line from the plane of elevation at the midship frame. Draw also the lines IK and LM, the one for the second deck, and the other for the sheer rail or top of the side in midships. The height of both are to be taken from the plane of elevation.

4thly,

4thly, Draw the line NO perpendicular to AB ; this is called the middle line, and represents the middle line of the stem and post, dividing the whole ship into two equal parts; and parallel to NO draw the lines AL and BM , to limit the breadth; also a line for half the thickness of the stem, and one for half the thickness of the post. Draw the lines ax parallel to NO , dividing the lines OA and OB into two equal parts. Draw also the diagonal GB . These lines being drawn, we may proceed to form the midship frame by some of the following methods.

METHOD I.

To form a Midship Frame, that shall be neither too sharp nor too flat.

Plate III. Fig. I] 1st, Divide the line ax , which marks the head of the floor timber into three equal parts; set off one from a to b .

2d, Divide the line dB , the distance betwixt the load-water line and the upper side of the keel, into seven equal parts; set off one of these from d to e , and from e to m , and draw the diagonal aV , which divide into two equal parts in the point n . *Note, the diagonal, aV , is wiped out, after finding the point n .*

3d. Describe an arch of a circle to pass through the points b and e ; make the radius the whole length and half the length of the line Be , so the center A may be found by describing an arch with that radius from e , and one from b to intersect one another in A , we shall only make use of that part of this arch betwixt l and m . Now, to find the other arches md , la , an , nV , it must be observed, that, in order to reconcile two arches, so as to make a fair curve, a straight line must pass through the centers of both, and through the points where they unite or touch one another; draw therefore the lines Am and Al , so shall k be the center of the arch md , and o the center of the arch la . Again, through the center o , draw the line ao , produce it to P , which will be the center of the arch an . Lastly, from P thro' n draw the line Ps , s will be the center of the inverted arch nV . *Note, the center s will be without the Plate.*

4th. To form the top timber, set back the tenth part of the half breadth, from K to S , upon the line of the second deck; describe an arch of a circle thro' the points d and S , taking $\frac{1}{2}$ of the whole breadth for the radius: Again, from the point M , upon the line LM , set back the fifth part of the whole breadth to l . Describe an arch of a circle thro' the points S and l , taking the diagonal GB for the radius. As this arch is inverted in respect of the arch dS , the center will be without the figure. This compleats the form of half the midship frame, and by the same operations we may find the other half.

It must be observed, that there is no regard had to the round of the beam in setting off the deck line or depth of the hold. ME-

METHOD II.

To describe a Midship Frame of a circular Floor.

Plate III. Fig. II.] From the center G, the point where the middle line intersects the deck line, making the half breadth the radius; describe the arch b, G, c, O : Let d be the head of the floor timber, and $d \times$ the rising. Assume the point f , according to what round you propose to give to the second futtock, and describe the arch df ; the center may be found as directed in the preceding method. Divide the arch cO into three equal parts; set off one from c to g , and from the center b , describe the arch $d g$; there remains only the inverted arch $g Y$ to be described; the center may be found as before directed.

METHOD III.

To draw a Midship Frame which shall be full.

Plate III. Fig. III.] 1st. Draw the rising and deck lines as before; let $b \times$ be the rising.

2d. Make db the side of the square $dbac$ equal to Cb the $\frac{1}{2}$ of the breadth.

3d. Inscribe the two quadrants ceb , and cfb , into the square.

4th. Divide the side ca into a certain number of equal parts in the points O, N, M, L, a ; draw the lines $iL, bM, \&c.$ perpendicular to ac .

5. Divide the line CG , the depth of the hold, after deducting the rising, into the same number of equal parts in the points E, F, I, K , and make the lines Ep, Fq, Ir, Ks , in the frame, equal to the lines $O t, N n, M e, L m$ in the square, describe a curve through the points G, p, q, r, s, b , and the remaining part of the frame may be described by the preceding methods.

METHOD IV.

To describe a Midship Frame for a very sharp Ship.

Plate III. Fig. IV.] Let the length of the floor timber be half the breadth as before, and the rising one fifth or one sixth of the whole length of the floor timber; lay this off from x to E , and describe a parabola through the points G, P, Q, E , of which the point G is the vertex, and GC the axis. This method is extracted from M. Bouguer. The parabola may be formed by the following method: 1. Through the point E draw the line Tx perpendicular to GC , and the line dE perpendicular to AG , and produce

produce the line CG to D . 2dly, Upon the line CD find the center of a semicircle that shall pass through the points T , d , and D , so shall GD be the parameter of the parabola, by which we may find any number of points through which the curve must pass: For instance, suppose it were required to find a point in the perpendicular XP , through which the curve must pass; upon the line GD find the center of a semicircle which shall pass through the points D and X ; this will intersect the line AG in b , make bP equal and parallel to GX , so shall P be the point required; in like manner, the points aQf may be found. The remainder of the curve from E to y will be composed of two arches, the one to reconcile with the parabola in the point E , and the other inverted to pass through the point y ; the center of which may be found by any of the preceding methods. In order to find the center of that which joins with the parabola, make TR equal to half the parameter GD , and draw the line ER , upon which find a point S for the center of the arch.

We might shew a great many more methods of describing this midship frame. It is very true, that great care ought to be had in forming this frame, because upon it chiefly depends the form of all the other timbers; I say chiefly, but not altogether; for two ships may be similar as to their midship frames, and yet very different afore and abaft; and though the artists should make themselves acquainted with all the different ways of forming this frame, I should recommend that method to them which is the simplest, and which gives them the most liberty to vary the form of it, according to every one's particular taste or fancy; and it is very possible there may be several other methods as easy and plain as those we have described. This frame being once formed, we may form all the rest upon the same plane. We shall, in the next place, shew the different methods used by the builders for that purpose.

The ancient builders, not being acquainted with the methods of laying down their designs in a draught, found out a mechanic way of doing this, only by help of the midship frame, which they might have formed by some of the preceding methods, or any other contrivance of their own; and though this method is defective in several points, yet as it is an ingenious contrivance, we shall give it a place here.

METHOD I.

Of forming the Timbers by a Mould made to the Midship Frame; a rising Staff and overcast Staff.

Plate III. Fig. VII.] 1st. Having formed the midship frame, and set off its scantlings, make a mould to fit both outside and inside, which may be called the bend mould. 2d.

2d. Draw the line Zx to limit the head of the floor timber at d ; let du be the rising, and draw the line au ; let t be the height of the rising line abaft, and draw the line dt to represent the floor heads, or floor ribband. Set off dx from d to H ; and from c , the head of the first futtock, to 6 , and divide each in six equal parts, being the number of frames from midships to the balance frame.

3d. Divide the line au into five equal parts, and set off two of them from a to S ; divide the line aS into the same proportion, that the part $A6$ of the base AC of the right angled triangle (*Fig. 5.*) is divided into, and transfer these divisions to the bend mould, and let them be numbered $0, 1, 2, 3, 4, 5, 6$, which points will give the narrowing of the floor, as we shall shew, after constructing the triangle. We shall only remark, that the line aS , which is $\frac{2}{3}$ of au , is nearly the difference betwixt half the length of the midship floor timber, and half the length of the floor timber at the balance frame. But as this appears to be too much, we may take $\frac{1}{3}$ as in the figure, or any other quantity which shall be thought most convenient.

To construct the Triangle, Fig. 5.

Upon the line AC , drawn at pleasure, set off any distance from A to 1 , and double that distance from 1 to 2 , treble from 2 to 3 , and so on in the same progression till we have as many divisions on the line AC as we propose to have frames abaft the midship. Erect a perpendicular at A , which may be produced at pleasure, and from any point B draw lines to all the divisions of the base AC . Observe, that though in the triangle we have drawn a line for every frame to the fashion piece, we shall only make use of six, there being so many to the balance frame. The triangle being thus constructed, apply the line aS to it, in such a manner, that it may be parallel to AC , and be contained betwixt the lines BA and $B6$, the lines drawn from the point B to the points $1, 2, \&c.$ will divide it into the required proportion.

To construct the Rising Staff, Fig. 5.

This staff KL may be of the same breadth with the keel, and a little longer than at , the height of the rising of the floor. In order to graduate that staff, set off xu , the rising of the midship floor from K to o , and make oL equal to at ; apply the line oL to the triangle, so that it may be parallel to the base, and contained betwixt the lines AB and BC the

E
lines

lines from the point B to the several points in the base will divide it into the required proportion, which will give the rising of the floor.

Note, Our author calls xu the acculement, and ud the rising; the line u a will pass through the point where the inverted arch joins the floor sweep.

To construct the over cast Staff, Fig. 5.

That we may have a clear understanding of what is meant by *over-cast*, it will be proper to observe, that in forming the frames by the bend mould, when it is set to the narrowing of the floor, the head of the mould will come too far in at the deck; the mould must therefore be moved round upon the point which represents the floor ribband, till the head goes out to the proper breadth; this will occasion the lower part of the mould to rise a certain quantity, which is called the over-cast. In order to graduate this staff we must determine the difference betwixt the main breadth at the midship frame, and at the balance frame, which suppose DF, let this be placed parallel to the base, and contained betwixt the line BA and B 6; so shall the lines B 6, B 5, &c. divide it into the required proportion.

These are the instruments that are necessary for forming the after frames, those for the fore part are constructed in the same manner, only the graduations for these are but half the graduations of the former, for which reason there must be another bend mould graduated for the forebody.

Now, in order to form the frames by these instruments, place the bend mould upon the rising staff in such a manner that the middle line of the staff produced may pass through the narrowing of the floor upon the bend mould, expressed by the division corresponding to the frame to be formed; suppose frame 6, (Fig. 7.) the lower or strait part of it expressed by the dotted line in the figure being applied to the rising staff, till the middle line Ba pass through the division 6 on the bend mould: mark by the edge of the rising staff the point 6, which expresses the rising of the floor at that frame. Set up the over cast (expressed by the space contained betwixt the points 5 and 6 upon the over cast staff) from the lower part of the bend mould to the point 6 upon the line Ba; then keeping the point d immovable, turn the bend mould upon this point till the lower part rise to the over cast at the point 6, upon the line Ba, and when in this position we may describe the curve to the floor head, and then invert the bend mould, and placing the point 6 (betwixt d and H) to the point set off before to express the rising, turn the mould
till

till the strait part touch the curve before described, and then draw the lower part, which compleats the frame.

This is the method that is used when they mould the timbers, and it may likewise be used to lay them down upon a draught; for if the line *au* of the bend mould (*Fig. 8.*) be laid upon the line *AV*, we may, when in that position, describe the midship frame from the point *d* to the point *x*. In like manner we may describe all the rest of the frames, by giving each its proper over-cast and rising; as for instance, if it were required to describe frame 6, take the rising *K 6* upon the rising staff, and set it off from the point *B* to the point *a* upon the line *B G*, and draw a line through the point *a* parallel to *AV*, upon which laying the bend mould in such a manner that the point 6, which expresses the narrowing of the floor, shall be upon the point *a*; then will the point *d* be upon the point *R*: Set up the proper over-cast from *a* to 6, and keeping the point *d* immoveable, push up the bend-mould, which at first was placed at the point *a*, till it be raised to the point 6, which will throw out the point *x* to the proper breadth at the deck. But because the deck is higher at timber 6 than at the midship frame. Take the distance betwixt *e* and 6, at the head of the futtock on the bend mould, and set it up from *x* to 6, and then inverting the bend mould, so that the point 6 betwixt *d* and *H* be at the point *X*, and the strait part of the mould touch the curve before described: we may then describe the lower part to the point *X*, which compleats the whole frame. The timbers for the fore body may be described by the same process as those of the after body, only making use of the bend mould, rising, and overcast staff, graduated for that purpose; but, as we observed before, we cannot lay down any timbers by this method, but those betwixt the midship and ballance frame.

The builders finding how very advantageous it would be for them to form all the timbers upon the plane of the projection, because they could then at one view see how they would compare one with another, have tried several expedients to perform this, of which I might instance ten or twelve, but shall content myself with explaining three, which may be sufficient for those purposes, in order to which I shall first shew another method of forming the midship frame, different from those we have shewn before.

Plate III. Fig. 6. 1st. Draw the rising deck, and load-water lines, and set off the length of the floor timber as before.

2d. Take one fourth of the length of the floor timber, and set it off from *O* to *d*, upon which erect the perpendicular *dc*, and divide it into two equal parts in the point *e*.

E 2

3d.

3d. Describe an arch through the point *a*, the head of the floor timber, and the point *e*, taking for the radius the distance from the upper edge of the keel to the port-sells, or a little more or less, according to what round you propose to the floor head. This determines the rising of the floor timber, and with the radius *O l*, half the length of the floor timber, describe the arch *e Y*, which determines the *aculement* of the floor timber.

4th. At the point *l*, the middle of the line *A O*, erect the perpendicular *l m*; and at the point *n*, the middle of the line *A l*, erect the perpendicular *n o*; erect also the perpendicular *p q* at the middle of the line *A n*; and another *r s*, at the middle of the line *A p*; and lastly, another *t u*, at the middle of the line *A r*.

5th. Take the distance *l n*, which set off on the line *n o* from *n* to *z*; and on the line *p q*, from *p* to *g*; then taking the distance from *a* to *g*, set that off from *p* to *y*; again take the distance *p y*, which set off from *r* to *b*, and the distance *b a* from *r* to *F*; and lastly take the distance *r F*, which set off from *t* to *E*, and then the distance *E a* from *t* to *X*, a curve passing through the point *a, z, y, F, X, T*, will form the midship frame under water. We may then set off half the thickness of the post and stem on each side off the middle line, and form the rest of the timbers; those for the fore body on the right, and for the after body to the left of the middle line.

Plate II. 1st. To lay down the post upon the plane of projection, take the difference of the draught of water abaft more than in midships, as marked on the plane of elevation (*Fig. 2.*) set off this from *F* to *e*; (*Fig. 3.*) and draw the line *d e* parallel to *A B*; take also *K F*, the height from the plane of elevation, which set off from *e* to *r*, so shall the point *r* be the head of the post.

2d. To lay down the wing transom, take its height from the plane of elevation, which set up on the plane of projection to *f*, and draw the line *g f* perpendicular to the middle line, so *g f* represents the upper side of the wing transom, without regarding the round up or the round aft. Take also the height of the rising line upon the post from the plane of elevation, which set off from *e* to *G*.

3d. To form the fashion piece; take upon the plane of the projection *n G* the height of the load-water line, above the rising line upon the post, which set off from *n* to *o* upon the water line; take also *G P*, the distance betwixt the rising line and lower deck, which set off from *P* to *q* upon the deck line, and describe a circle through the points *f, q, o*. There is a problem in geometry to find the center of this arch. *Note*, the point *q* may be taken further out or in, as you design a lank or full fashion piece.

Lastly,

Lastly, describe the arch σG ; the radius of this arch may be the main half breadth; so shall f, q, o, G , be the form of the fashion-piece, which may be varied according to the fancy of the artist, by altering the centers.

Having thus formed the midship and after-frames, we shall, in the next place, shew how to space the ribband lines, which are represented by the diagonals in the figure; but it will be proper to remark, that the ribbands are thin narrow planks, which are made so, that they may easily be bent to the timbers. That which is nailed to the post at the height of the rising line, and to the midship frame, at the end of the rising of the floor timbers, is called the floor ribband. That which answers to the wing transom and to the height of the lower deck, on the midship frame, is called the breadth ribband; all the rest betwixt these two are called intermediates.

From the point H draw the line HG for the floor ribband, and from the point T draw the curve T, E, q, p for the breadth ribband, and draw the two intermediates betwixt them, so that by them the curve of the midship frame and fashion piece may be divided into three equal parts.

Now, it is very plain, that if the ribbands had a proper form, and nail'd at the proper heights and positions, they would compose a kind of a model, by which the circular form of every timber might easily be discovered; but as we have only the extreme points of each given, we cannot from thence form such a curve as shall be necessary. We must therefore find a method to form some intermediate timbers betwixt the midship and after one, and thereby form the ribbands so that they shall make fair curves. There are some preliminary operations which are necessary towards performing this.

1st. *To construct an equilateral Triangle for the Progression of the Frames in the After-Body.*

Plate IV. Fig. I. From the point M set off any distance to 1, upon any strait line, and from 1 to 2 treble that distance, from 2 to 3 five times that distance, from 3 to 4 seven times that distance, and proceed in that progression, increasing the spaces betwixt the figures by equal differences, viz. double the distance betwixt M and 1, till we have as many divisions less one as there are frames betwixt the midship and post, including that of the midship and post; and because there are nine frames the line must consist of ten divisions, from the point M to the point E . Let them be numbered 1, 2, 3, &c. make ME the base of an equilateral triangle SME , and draw the lines $S1, S2$, &c. observing to produce them all till the distance betwixt the lines SE and $S9$, upon a line parallel to the base, be at least equal to the distance betwixt the frames in the plane of

of elevation. The line SM represents the midship frame, and the line SE, the post, and the nine intermediates represent the nine frames betwixt the midship and post.

In order to give us a clear understanding of the use of this triangle, it will be necessary to remark, that the midship frame being that which incloseth the greatest space, and the aftermost that which incloseth the least, it will follow, that the intermediate frames will partake of the form of each, but mostly of that to which they are nearest; yet they will still retain a little of the form of each. Hence, when the intermediate frames are all formed, their curves will divide all the diagonals, drawn in the plane of projection, into as many parts as there are frames; and all the methods the builders have invented serve only to divide them into such a proportion as shall produce the fairest curves.

Now, if the proportion pitched upon for that purpose, be as 1, 3, 5, 7, 9, &c. then they must all be divided into the same proportions as the base of the triangle is divided into; and this may be performed very readily, only by taking the length of each diagonal from the plane of the projection, and applying it to the triangle in such a manner that it shall become the base of an equilateral triangle; as for instance, to divide the first intermediate diagonal, take the length of it in the plane of projection, (*Plate II. Fig. 3.*) and set it off from the point S to *m* and *k* on the sides of the triangle SM and SE; and draw the line *mk*, which being parallel to the base of the triangle, will be divided into the same proportion. In like manner, all the rest of the diagonals may be divided; but as the builders are not agreed as to the precise form of a ship's bottom, some chuse to divide the base of the triangle into another proportion; others again, in applying the diagonals to the triangle, give them different inclinations to the line MS. It would be very proper to try several of these methods, by which means we might discover which would be most convenient; and after all the diagonals are divided into as many points as there are frames, curves passing through these points will determine the form of all the frames from the midship to the post. It only remains to shew how to end each frame upon the post. It was before observed, that the keel is not parallel to the surface of the water, so that it will be very easy to conceive that the height of each frame, taken from the upper side of the keel, upon a perpendicular to the surface of the water, will always increase, the nearer the frame is to the stern post. Now, *g* K is what the keel is deeper abaft than at the midship frame; and to find how much any frame abaft exceeds that of the midship, suppose the first, take the distance betwixt the line *g* G and K I at that frame, from the plane of

of elevation, (*Plate II.*) which set off from F towards *d*, (*Fig. 3.*) and at that point draw a line parallel to *de*, which will be the first frame upon the keel. In like manner we may draw lines parallel to *de*, for all the rest, as in the figure, which will determine their heights from the upper side of the keel to the surface of the water.

It must be observed, that the diagonals in the plane of the projection, which end on the fashion piece, must likewise end on the fashion piece on the plane of elevation; we must therefore draw the fashion piece on the plane of elevation. Thus, take the distance of the point G, in the plane of the projection, from the upper side of the keel, which set off upon the stern post in the plane of elevation to the point *b*; through *n*, the rabbit of the wing transom, draw the strait line *bM*, which will represent the fashion piece on the plane of elevation. Now, as only the lowest diagonal ends upon the post, in the plane of projection, which in the plane of elevation ends at *b*, so the other diagonals that end upon the fashion piece, must likewise end on the fashion piece in the plane of elevation. Their height must therefore be transferred from the plane of the projection to that of the elevation; so the second diagonal will end at the point P, upon the fashion piece in the plane of elevation. In like manner all the rest may be transferred to the plane of elevation; and as the line that represents the fashion piece upon the plane of elevation rakes aft, this will occasion the line PS, which is perpendicular to the line that represents frame 9, to exceed the line *bM*. In the triangle, the line SM represents the midship frame, and the line SE the post; that is, if the point where the ribband ends on the post, be equally distant from frame 9, that frame 9 is from frame 8. Now, as *Mb* is longer than *ML*, we must draw the line SD without the triangle, which is to be used instead of the line SE, when we come to apply the diagonal HG to the triangle; for the point H must touch the line SM, and the point G the line SE. To find the point D, take *ML* from the plane of elevation, and apply it to the triangle, so that BC shall be equal to it, and parallel to ME; it must also be contained betwixt the line Sg and SE. Then take *bM*, and set it off from B, which will give the point D. In like manner the line SF must be used, when we divide the diagonal MK; and to find the point F, set off PS, in the plane of elevation, from B to F in the triangle; and draw the line SF. In the same manner there must be lines drawn for every diagonal without the line SE; so the line SE is not used in dividing the diagonals. Let it be further observed, that in applying each diagonal to the triangle, it must not only be contained betwixt the line SM, and the line corresponding to the diagonal, which is to be divided, but it must likewise form a certain angle with the line MS, that

that is, with that part of it which is intercepted betwixt the diagonal and the point S. These which appear to me to be properest for that purpose are as follows: The first diagonal to make an angle of 60 degrees; the second 62½, the third 63, the fourth 86, the fifth 65, the sixth 60 degrees; but the artists vary these angles according to the form they design to give to the timbers; nay, some draw them always parallel to the base of the triangle.

Our author then proceeds to the forebody, and forms a triangle, the base of which he divides in the same manner as that already described, by which he divides each diagonal. He likewise shews how to space the diagonals upon the stem; but as the artists leave us so much undetermined as to the angles that each diagonal is to make with the line S M, when they are applied to the triangle, it will be very difficult to apply this method to practice. So we presume it will be needless to say any more on that head, judging what has been already said sufficient to give our readers an idea of the principles on which the method is grounded; we shall proceed therefore to the next method he proposes.

To form the Timbers by a Quarter of a Circle. Plate IV. Fig. 2, 3.

1st. Form the midship frame, the fashion piece, the foremost timber, also the two balance frames, by some of the preceding methods. *Note, Those who make use of the following method of forming the rest of the timbers, are supposed to be previously acquainted with the manner of forming the midship frame, &c.*

2d. Space all the diagonals for the ribbands as directed in the preceding method.

3d. From the center A, with any radius, describe a quarter of a circle, and divide it into so many equal parts, that there may be a point for each timber to be formed, and draw the radii A 1, A 2, &c. to A 9, so we shall have one for each frame.

4th. Take *a b*, the first diagonal, which set off from the point A upon the line A C, to 1.

5th. Take *a c*, the distance upon the lower ribband, betwixt the post and balance frame, which in the plane of projection is the 6th frame, set off this distance upon a perpendicular erected upon the line A B, to intersect the radius A 6, in such a manner that the perpendicular G 1 shall be equal to *a c*.

6th. Produce the line C A to F, and upon this line find a point, which shall be the center of a circle whose circumference shall pass through the point 1, before marked upon the line A C, and the point 1, now marked upon the radius A 6; describe the arch through these two points to the point 1 on the line A B.

7th.

7th. Let fall perpendiculars to the line A B from the points where the arch 1, 1, 1, intersects the several radii. Transfer these perpendiculars to the line *a b*, which will divide the lower diagonal into the points through which the curves of the frames must pass. *Note, the perpendiculars are not drawn, to avoid confusion.*

After the same manner all the other diagonals are graduated, first by taking the whole length of each diagonal, and setting them up on the line A C, from the point A to the points 5, 4, 3, 1, 2, and secondly, by taking the several distances upon each diagonal intercepted betwixt the after frame and the balance frame, and applying them severally to the radius A 6, in such a manner that they shall be contained betwixt the radius A 6 and the line A B, upon the perpendiculars let fall from the points 5, 4, 3, 1, 2. And, thirdly, by describing arches through the points in the line A C, to pass through the points of the same number upon the radius A 6, whose centers are in the line A F; the arches to be produced to intersect the line A B in the points 5, 4, 3, 1, 2, will intersect all the radii; the perpendiculars let fall from the intersections of the radii with the arch corresponding to each diagonal, will divide that diagonal into the points through which the curves of the frames must pass.

The diagonals for forming the frames in the fore body are divided into the points through which the curves must pass by the same operations, only observing that frame 4 is the balance frame for the fore body.

C H A P. V.

Of the Projections on the horizontal Planes, and of the Water and Ribband Lines on the Plane of Elevation, and that of the Projection.

W A T E R Lines are described upon a ship's bottom by the surface of the water into which she swims; that which determines how much is under water when she is loaded is called the load-water line. Now it is plain, that if a ship is lightened, she will rise higher out of the water; and if she be lightened so as to rise equally afore and abaft, the surface of the water will then form another water-line parallel to the load-water-line. Again, if the ship is lightened more, she will still rise higher; and if the same difference still continues betwixt the draught of water abaft and afore, we shall have another water line parallel to the two former;

F

W

so that by this means we may describe as many water lines as we please, all parallel to one another.

In order to form an idea how these lines are represented on the different planes, let us suppose a ship upon the stocks upon a level ground, and her keel in the same position, with respect to the horizon, that it is to be in the water when loaded; we may then describe several black lines upon the ship's bottom, which may be whitened for that purpose, all parallel to the horizon: These will all be water lines.

Now, if a spectator be removed at any considerable distance from the ship upon a line in the same direction with the keel, all these black lines, which were drawn upon the ship's bottom, parallel to the horizon, and which are actually curves, will appear to him all strait lines, because he sees them all upon a plane formed by a section passing through the midship frame perpendicular to the keel. Hence the water lines will be represented by strait lines upon the plane of the projection.

Again, if a spectator is removed at any considerable distance from the ship upon a line perpendicular to the keel, so as to see the whole length of the ship at one view, the water lines will then appear to him strait lines, because he sees them upon a plane erected perpendicular to the horizon upon the middle line of the keel. Hence the water lines will be represented by strait lines upon the plane of elevation.

But if the spectator be supposed to be placed underneath the middle of the ship, at any considerable depth, in a line perpendicular to the level ground, he will then, viewing the ship's bottom upwards, discover the curvings of all the water lines. These curves are all projected upon a plane, which we must imagine to be formed by a section of the ship through the load-water line, and we are now to shew how these are formed.

To form the Water Lines upon the Horizontal Plane.

Let the water lines to be formed be represented in the plane of the projection by strait lines, all parallel to one another. These will be represented by the strait lines in the plane of elevation. Suppose gr , st , bx , and TV , all parallel to one another, and the same distance from the load-water line TV that the lines which represent them in the plane of the projection are from it. In order to form these upon the horizontal plane,

1st, Take half the thickness of the post from the plane of the projection, and lay it off on the horizontal plane from A to E , and through the point

point E draw the line *E s* parallel to *AB*, five or six feet long; lay off the same distance from *B* to *F*, and thro' the point *F* draw a line *F R* parallel to *AB*, five or six feet long.

2d. From the points where the water lines intersect the stern post upon the plane of elevation, let fall perpendiculars. In like manner, let fall perpendiculars from the points where the water lines intersect the stem.

3d. Take upon the water lines, in the plane of the projection, the several distances intercepted betwixt the middle line and the curve of the midship frame, and lay them off from the line *AB* in the horizontal plane, upon the perpendicular that represents the midship frame. Take also from the plane of projection the several distances intercepted betwixt the middle line and the curvings of the other frames, and lay them off in the horizontal plane from the line *AB*, upon the perpendiculars corresponding to their respective frames, both in the fore body and after body, and curves passing through all these points will give the true form of all the water lines; they end forward at the points where the perpendiculars intersect the line *F R*. The water lines abaft which end upon the post in the plane of elevation, will end where the perpendiculars intersect the line *E s* upon the horizontal plane. But the 3d and 4th water lines cannot end upon the post, by reason of the fashion pieces; and in order to find the points where these shall end, we must proceed in the following manner.

To find the point where the load-water line ends, let fall a perpendicular from the point *k*, where it intersects the fashion piece on the plane of elevation, to *N*. Take from the plane of the projection upon the line that represents the load-water line, the distance betwixt the fashion piece and the mid-line; lay this off upon the horizontal plane from the line *AB* to the point *N*, which will end the load-water line upon the horizontal plane, from whence it may be drawn to *g*; so *g N* will be the flat of the Tuck; and to find the point *g*, draw a line parallel to *k N* thro' the point where the line *T V* cuts the rabbit of the post, which will give the point *g*. We may, after the same manner, find the ends of the other water lines that do not go to the stern post for a square tuck.

To form the Ribbands upon the Horizontal Plane.

We observed before, that the ribbands where thin planks nailed to all the frames from the post to the stem; and that when they are carried round, so as to make fair curves, the form of all the filling timbers may be by them determined. These filling timbers are to be placed betwixt

the frames, which were methodically laid down in the draught. We shall here further observe, that these ribbands will round two ways, one in a vertical, and one in an horizontal sense, occasioned by the nature of the form of the ship's body; for they will, in carrying them about, naturally fly higher abaft and before than they are in midships, which gives them a vertical curve, and the narrowing of the ship's breadth from the midships both ways, gives them the horizontal curve; thence they will be represented by different lines on all the planes.

They are represented upon the plane of the projection by straight lines, all but the breadth ribband, which is usually represented by a curve; but upon the plane of elevation, and that of the horizon, they will be represented by curves. The reason of these different appearances arises from the different situations in which they are supposed to be viewed, as was observed in respect of the water lines.

Now, in order to comprehend the relation betwixt these horizontal curves, and the lines that represent them upon the plane of the projection, it will be sufficient to remark, that these horizontal curves result from the different lengths of the perpendiculars that are supposed to be drawn in the plane of the projection, from the points where the lines that represent the ribbands intersect the frames, to the middle line. Hence, if the lengths of these perpendiculars are transferred to the lines corresponding to each frame in the horizontal plane, we shall have the points thro' which the curve that forms the ribband must pass.

But if these ribbands are to be represented upon a plane placed in an oblique position to the horizon, that is to say, a plane that has the same inclination to another plane erected perpendicularly upon the middle line of the keel, that the line that represents that ribband, has to the middle line in the plane of the projection; in that case, they will have a quite different form from what they have upon the plane of the horizon.

Now, to conceive the relation betwixt these and the lines that represent them upon the plane of the projection, it will be sufficient to remark, that if the several distances taken upon each diagonal intercepted betwixt the middle line and the points where these diagonals intersect the curves of the timbers in the plane of the projection; I say, if these be transferred to the lines that represent those timbers, we shall have the points thro' which the curves that form the ribbands must pass.

Again, if these ribbands are to be represented upon the plane of elevation, they will have a different form from any of the former; to find which, we need only take the perpendicular distances from the points where the diagonals intersect the curves of the timbers in the plane of

of the projection to the line that represents the upper side of the keel, and transfer them to the plane of elevation, setting them up from the upper side of the keel upon the line corresponding to the timber, from which they were taken upon the plane of the projection. This will give us the points thro' which their curves must pass.

Having thus given a general description of these curves, we shall now proceed to describe them upon the different planes.

To describe the Floor Ribband upon the Plane of Elevation.

1st. Take the perpendicular distance betwixt the point *a*, where the diagonal intersects frame 9, and the lower water line in the plane of the projection.

2d. Set up this distance from the point *S*, where the lower water line intersects frame 9 in the plane of elevation, and we shall have a point *G*, thro' which the curve must pass.

Now, it is plain, that we may, by repeating the same operations, have a point in each frame, thro' which the curve of the ribband must pass upon the plane of elevation. After the same manner are all the other ribbands formed.

To describe the Ribbands upon the Horizontal Plane.

The breadth ribband is formed by transferring the lengths of all the perpendiculars that are supposed to be drawn from the points where the curve that represents this ribband intersects the timbers, to the middle line in the plane of the projection: This curve, in the plane of the projection, is drawn from the breadth in midships to the extremity of the wing transom.

1st. Lay off the length of the wing transom upon the perpendicular *N L*:

2d. Take the length of the perpendicular drawn, from the point where the curve that represents the breadth intersects frame 9, to the mid-line in the plane of the projection; lay off this from the line *A B* upon the perpendicular representing frame 9 in the horizontal plane, to the point *S*, which will be one of the points thro' which the curve of the ribband must pass. We may proceed in the same manner to find points upon all the perpendiculars, both afore and abaft, so shall the curve *L, S, Q, 1*, be the form of the breadth ribband. But to compleat this ribband, the round aft of the wing transom must be set off.

To form the Oblique or Cant Ribbands.

We observed before, that these ribbands could not be formed either upon the horizontal plane or that of elevation, upon which account they were seldom drawn, because each must be drawn upon a separate plane. However, those who incline to draw them may use the following method :

Let it then be required to form the first ribband represented in the plane of the projection, by the diagonal H G.

1st. Produce line H G to the point *p* in the middle line upon the plane of the projection.

2d. Take the height of the point *p* above the line that represents the upper side of the keel in midships, in the plane of the projection ; set up this from the same line in the plane of elevation, on a perpendicular, upon the post, from which point let fall a perpendicular to the point F in the line C D, and produce all the perpendiculars that represent the frames to the line C D ; so F Q will be the axis of the ribband from the post to the midships.

3d. Take upon the plane of the projection, in the line H *p*, the distance *p* G, which set off upon the perpendicular from the point F to *f*.

4th. Take the distance on the diagonal from the point *p* in the middle line to its intersection with the frame 9. Set off this from the line C D upon the perpendicular corresponding to frame 9 ; this will give us a point thro' which the curve must pass. Do the same for all the other frames to the midship.

In like manner the curve for the fore part of the ribband is formed from the intersections of the diagonal 4, 5, with the curves of the frames in the plane of the projection ; but it is evident, this is a different plane from that of the line H *p* ; therefore we must have a different axis for the curve of the fore part of the ribband. In order to which, take from the plane of the projection the diagonal 4, 5 ; set off this from the point O to Z, and draw the line Z X parallel to C D. We must likewise take the height of the point 4 in the plane of the projection, and set it up on the stem ; from which point letting fall a perpendicular to the line Z X, we shall limit the fore end of the ribband. The points thro' which the curve must pass will be found the same manner as those for the after-body.

The builders make use of the cant ribbands to find the bevellings of the timbers ; for we must represent each frame as one intire piece of circular timber, and being all fastened to the keel they form the side of the ship. They are square upon the upper side of the keel ; but because both

both the outside and inside of the ship's sides, length-ways, form curves, it is plain, that the sections of any of the frames, the midship only excepted, will produce a surface in the form of a lozenge or rhombus; the angles which are formed by these sections are what are called the bevellings of the timbers.

The ship-wrights take these angles mechanically by an instrument called a bevel; thus they draw, upon the plane of the ribband, a line parallel to that which represents the frame, and distant from it the whole breadth of the timber; and applying the stock of the bevel to the line that represents the frame, and the tongue to the ribband, they have the quantity of the angle which forms the bevelling of the timber at that place.

It is plain the angle b, a, c , which points to the midship frame, will be obtuse, whereas the angle b, a, d , which points to the post, will be acute.

Now, as every timber has two planes, that which points to the midships will have what they call a standing bevelling, and that which points either to the post or stem will be under bevelling.

We shall shew in another place how the modern builders, by putting the frames in an oblique position to the keel afore and abaft, lessen the bevellings.

CHAP. VI.

Another Method of laying down the Horizontal Plane, and the Plane of Projection.

THOSE who are well versed in the art of drawing have taken a method quite different from any of those we have described, which shall be the subject of this chapter.

After forming the plane of elevation, and drawing all the perpendiculars for the frames, as before, the following method must be observed:

I.

To lay down the Breadth Ribband on the Horizontal Plane.

The extremities of it on the stem and post, and the point thro' which it is to pass on the midship frame are found as directed in the preceding chapter. It remains now to find the points in the balance frames, thro' which it is to pass.

To find the point in the fore balance frame take $\frac{11}{16}$ parts of half the main

main breadth, which set off on the line that represents that frame in the horizontal plane from K to L.

To find the point in the balance frame abaft, take $\frac{3}{16}$ parts of the half of the main breadth from M to N. It will be necessary to have another point in the fore body, thro' which the curve must pass; for which purpose use the following method:

Divide the space contained betwixt the line that represents the balance frame afore and the rabbit of the stem, into two equal parts, and draw the line *op*, on which set off the 160th part of the main breadth, which will give the point *p*, thro' which the curve is to pass. It must be observed, that the proportions for finding these points may be varied according to the form we propose to give to the ribband. After the points H, N, Q, L, *p*, *s* are thus set off, we may describe the curve either by moulds or penning battens.

II.

To lay down the Floor Ribband on the Horizontal Plane.

1st. The height of this ribband must be determined both upon the post and stem, from which points letting fall perpendiculars, we shall have the extremities of it on the horizontal plane, observing to allow for the rabbit.

2d. Take half the length of the midship floor timber, and set off on the line that represents the midship frame on the horizontal plane from *a* to *s*, which will be the point thro' which the curve must pass.

3d. Take $\frac{1}{16}$ of the line *as*, the breadth at the midship frame, and set it off on the balance timber afore, from K to T, and set off $\frac{1}{16}$ of the same line, upon the balance timber abaft to V, and draw the curve thro' the points G, V, S, T, R.

III.

To lay down the after Balance Timber upon the Plane of Projection.

1st. Produce the line which represents it on the horizontal plane to the sheer rail, on the plane of elevation, and take the distance upon this line betwixt the upper side of the keel, and the lower edge of the second wale, which here represents the breadth ribband; set up this from A to C on the plane of the projection, from which point draw the line CD, perpendicular to the middle line. (Plate II. Fig. 1, 2, 3.)

2d. Take the line MN in the horizontal plane, and set off from D to E, which will give one point, through which the curve of the timber must pass.

3d. Take

3d, Take the height of the floor ribband, in the plane of elevation, and set it up on the plane of the projection to G; from the point H, at the end of the floor timber, draw the line H G, which will represent the floor ribband on the plane of the projection. (*Plate II. Fig. 1. 2. 3.*)

4th, Take the distance M V, in the horizontal plane, with a pair of compasses, and move the compasses with one foot, in the middle line, and the other in a line perpendicular to it, till it intersect the diagonal in the point L, thro' which the curve of the frame must pass. To those who are acquainted with drawing, the three points E, L, F, will be sufficient to form the timber; they who incline to have another point may divide the line A C into two equal parts by a perpendicular M K, drawn to the middle line, from which setting off $\frac{1}{16}$ of the line M K, we shall have another point thro' which the curve must pass.

IV.

To lay down the ninth Frame abaft on the Plane of the Projection.

Take the height of the breadth ribband at this frame, in the plane of elevation, and set it up on the plane of the projection from F to O, and draw the line O P perpendicular to the middle line. (*Plate II. Fig. 1. 2. 3.*)

2d, Take the distance X S in the horizontal plane, and set off from O to P, which will be the point thro' which the curve must pass.

3d, Take the distance X Z in the horizontal plane, which set off from the middle line, to intersect the diagonal that represents the floor ribband, in the plane of projection in Q, observing to keep the compasses as before directed.

4th, Divide the line K O in two equal parts, and draw the line R S perpendicular to the middle line, on which set off $\frac{1}{16}$ of the line P O, from R to S, and draw the curve thro' the points P, S, Q, F, which will be the form of the ninth frame.

V.

To lay down the intermediate Ribbands abaft on the Plane of the Projection.

1st, Take the distance betwixt the upper side of the keel and the breadth, upon the line that represents the midship frame, in the plane of elevation, and set it up from A to T, and from B to T, in the plane of the projection, so shall the line T T give the height of the breadth ribband in midships.

2d, Divide the curve H M T into as many equal parts as there are to be intermediate Ribbands; divide also the curve of the ninth frame Q S P into the same number, and, thro' these divisions, draw the diagonals which will represent the ribbands as in the plate.

VI.

To lay down the first intermediate Ribband upon the Horizontal Plane.

1st, Take the nearest distance of the point V (which is the extremity of the diagonal in the plane of the projection) to the middle line OF, set off this on the line which represents the midship frame in the horizontal plane, which will give the point thro' which the curve must pass at that place. After the same manner we may find the points in the lines that represent the balance and ninth frames in the horizontal plane.

2d, Take FZ, the height of the ribband upon the rabbit of the post, in the plane of the projection, and set it up on a perpendicular, to the point *k*, on the line that represents the rabbit of the post in the plane of elevation; take the nearest distance of the point *k* to the perpendicular of the post, which set off from F to *e*, and this will be the end of the ribband: So a curve passing thro' the points *e*, *d*, *c*, *b*, will be the form of the ribband.

VII.

To lay down the Wing Transom upon the Plane of the Projection, and on the Horizontal Plane.

1st, Take the height of the upper side of the wing transom (including the round up) in the plane of elevation, and set it up in the plane of the projection to the point *e*.

2d, Take the height in the plane of elevation, without regarding the round up, and set off from F to *f*, and draw the line *fg* perpendicular to the middle line, on which set off the length of the transom from *f* to *g*, this is equal to the line GH in the horizontal plane. The curve *ge* represents the upper side of the wing transom.

The round aft of the transom is represented upon the horizontal plane by the curve I. *k e*; H L is the square end of it.

VIII.

To lay down all the Frames in the after Body.

All these are laid down in the same manner as the ninth and balance frames before described, that is, by taking the half breadth of the ribbands at each frame in the horizontal plane, and setting them off from the middle line in the plane of the projection to intersect the diagonal corresponding to the ribband, as directed in forming the balance frame, by this means we shall divide each into as many points as there are frames: The curves drawn thro' these points will give the form of all the frames in the after body.

IX. To

IX.

To lay down the Position of the Fashion Piece on the Horizontal Plane.

Let fall the perpendicular GH , from the end of the wing transom, and draw the line HI , which will represent the plane of the fashion piece upon the horizontal plane, observing to make the angle GHI , about 25 degrees.

X.

To form the Fashion Piece in the same manner it is to be, when put into its proper place in the Ship.

The fashion piece laid down in the plane of the projection, regards that frame as it would appear when viewed from abaft; but as the fashion pieces on each side are not in one plane, as all the rest of the frames are, we shall be much deceived, if we imagine that the fashion piece laid down in the plain of projection, will give the true form of that which is to be put in the ship. We must therefore lay it down upon another plane, and, to avoid confusion, we shall separate it from the plane of projection.

Note, The fashion peice, mention'd by our author, described in the plane of the projection, is that betwixt the ninth frame, and the curve $f q o G$, which represents the fashion piece of a square tuck; it is formed in the same manner as the rest of the frames, by transferring the lines $n m, p o$, &c. in the horizontal plane, to the plane of projection, to intersect the diagonals corresponding to these ribbands in the points i, l , &c.:

1st, Draw the line $f G$, to represent the middle line of the plane of projection. (Fig. 4.)

2d, Draw the line $f g$ perpendicular to $G f$, to represent the wing transom.

3d, From i , the point where the fashion piece intersects the floor ribband in the plane of the projection, take the nearest distance to the line $f g$, which represents the wing transom, and set off this distance in Fig. 4. from f to b , and draw the line $b l$ parallel to $f g$.

4th, From the point l , where the fashion piece intersects the first intermediate diagonal, in the plane of projection, take the nearest distance to the line $f g$, set it off from f to k , in Fig. 4, and draw the line $k m$, parallel to $f g$.

5th, In like manner, the points where the fashion piece intersects the second and third diagonals in the plane of projection, are to be transferr'd to the points q and n , Fig. 4, and the lines $p q, n o$, drawn parallel to $f g$.

G 2

6th,

6th, To find the points through which the curve must pass: Take the line II , which represents the position of the fashion piece upon the horizontal plane; lay this off from f to g : Again, take the distance ly in the horizontal plane; which lay off from g to p , in like manner set off the distance lz , from n to o ; and the distance lp from k to m , and lastly, the distance ln , from b to l ; so a curve drawn through the points g, p, o, m, l , will give the true form of the fashion piece.

XI.

To lay down the Fashion Piece upon the Plane of Elevation.

1st, Take the several heights above the keel, of the points where the fashion piece intersects the diagonals in the plane of projection, and transfer them to the lines o, p, q, z, y , in the plane of elevation, drawn parallel to the keel, and the same height above it, that their corresponding points are in the plane of projection.

2d, Take the nearest distance of the point n , in the horizontal plane, to the line CF , the perpendicular from the head of the post, set off this from the same line in the plane of elevation upon the line p ; which will be the point through which the curve must pass.

3d, In like manner the points z, y , must be transferr'd from the horizontal plane, to the plane of elevation in the points z, y , a curve passing through these points will be the projection of the fashion piece on the plane of elevation.

We shall hear remark, that some builders to avoid giving a great bevelling to the timbers, and likewise that they may not require such compass timber, do change the direction of all the frames in the fore-body before that of the loof; that is, the lines that represent them in the horizontal plane make an acute angle with the line that represents the keel; these are called cant timbers, and may be formed in the same manner as the fashion piece, which we have now described. Tho' several builders form all the frames perpendicular to the keel, to have the floor timbers in one piece, which will be much stronger than when in two pieces, and this will inevitably be the case when the timbers are canted.

We might here shew how to lay down the top timbers, but as that part under water is the most material, we shall proceed to form the timbers afore.

XII.

To lay down the Frames for the Fore-body.

The balance and the eighth frame must first be formed in the same manner as the balance and ninth frame abaft: In order to which the curve that

that represents the breadth ribband must be laid down in the plane of the projection afore. The diagonal, which represents the floor ribband, must likewise be laid down in the plane of the projection, for which purpose we must take the height of the ribband above the keel, upon the rabbit of the stem, and set it upon the line that represents the rabbit of the post in the plane of the projection, to the point 4; from which draw a line to the floor head, so 4 5 will represent the floor ribband.

XIII.

To space the Diagonals that represent the Ribbands afore, in the Plane of the Projection.

1st. As the points of their intersection at the midship frame are the same afore that they are abaft, we need only transfer them from abaft to the fore body.

2d. Take the height of the breadth ribband upon the stem, in the plane of elevation, and set it up from F to 17 in the plane of projection.

3d. Divide the distance betwixt 4 and 17 into four equal parts, which will give the points in the plane of projection, where the immediate diagonals end on the stem.

After the diagonals are drawn in the plane of the projection, the ribbands may be laid down in the horizontal plane, and from thence all the other frames may be laid down in the plane of projection, in the very same manner that the horizontal ribbands and the frames for the after-body were laid down.

General Remarks on Ship Building.

ALL the rules we have hitherto laid down, collected from the principal dimensions of ships built by the most eminent masters, should only be so far regarded as they may assist the artist in forming the body in such a manner as to produce effects answerable to the service for which the vessel is designed.

In order to qualify a builder for such an undertaking, it is necessary he should understand the nature of fluids, and of such bodies as will float in the water; when he has made himself acquainted with these, I would recommend him to M. *Bouguer's* treatise on ship-building.

The principal Qualities belonging to Ships.

1st. To be able to carry a good sail, not only because, in forming the body, the water lines are all supposed to be described when a ship is upright in the water, but likewise for doubling a cape, or getting off a lee shore, which will be impossible to be done when a ship lies over in the water, this will likewise render her lower tier, if not all her guns, useless.

2d. A ship should steer well, and feel the least motion of the helm.

3d. A ship should carry her lower tier of guns four feet and a half, or five feet out of the water, otherwise a great ship, that cannot open her ports upon a wind, but in smooth water, may be taken by a small one, that can make use of her guns, or she must bare away before the wind, to have the use of her guns; on which account it will be proper to raise the ports higher before than in midships, because the fore part of the ship is often pressed into the water by carrying sail.

4th. A ship should be duly poised, so as not to dive or pitch hard, but go smooth and easy through the water, rising to the sea when it runs high, and the ship under her courses, or lying to under a mainsail, otherwise she will be in danger of carrying away her masts.

5th. A ship should sail well before the wind, large, but chiefly close hauled, keep a good wind, not fall off to the leeward.

Now the great difficulty consists in uniting so many different qualities in one ship, which seems indeed to be impossible; the whole art therefore consists in forming the body in such a manner, that none of these qualities shall be entirely destroyed, and in giving the preference to that which is most required in the particular service for which the vessel is built; in order to which

which, it will be necessary to know, at least nearly, what form will give a vessel one of these qualities, considered abstractly from the rest.

To make a Ship carry a good Sail.

A flat floor timber, and somewhat long, or the lower futtock pretty round, a freight upper futtock, the top timber to throw the breadth out aloft; at any rate to carry her main breadth as high as the lower deck: Now, if the rigging be well adapted to such a body, and the upper works lightened as much as possible, so that they all concur to lower the center of gravity, there will be no room to doubt of her carrying a good sail.

To make a Ship steer well, and quickly answer the Helm.

If the fashion pieces be well formed, and the tuck carried pretty high; the midship frame carried pretty forward; a considerable difference of the draught of water abaft more than afore; a great rake forward, and none abaft; a snug quarter-deck and forecastle, all these will make a ship steer well; but to make her feel the least motion of her helm, it will be necessary to regard her masts. There is one thing not to be forgot, that a ship which goes well will certainly steer well.

To make a Ship carry her Guns well out of the Water.

It is plain, that a long floor timber, and not of a great rising; a very full midship frame, and low tuck with light upper works, will make a ship carry her guns high.

To make a Ship go smoothly through the Water without pitching bard.

A long keel, a long floor, not to rise too high afore and abaft, the area or space contained in the fore body, duly proportioned to that of the after body, according to the respective weights they are to carry; all these are necessary to make a ship go smoothly through the water.

To make a Ship keep a good Wind.

A good length by the keel, not too broad, but pretty deep in the hold, which will occasion her to have a short floor timber, and great rising.

As such a ship will meet with great resistance in the water, going over the broad-side, and little when going a-head, she will not [fall much to the leeward.

Now, some builders imagine that it is not possible to make a ship carry her guns well, carry a good sail, and to be a prime sailer, because it
would

would require a very full bottom to gain the first two qualities, whereas a sharp ship will best answer for the latter; but when it is considered that a full ship will carry a great deal more sail than a sharp one, a good artist may so form the body as to have all these three good qualities, and likewise steer well, for which purpose I would recommend somewhat in length more than has been formerly practised.

After what has been said upon this head, I believe it will not be thought impossible to unite all these different qualities in one ship, so that all of them may be discerned in some degree of eminence; but when it happens otherwise, the fault must be owing to the builder, who has not applied himself to study the fundamental rules and principles of his art.

Excepting some antient builders, who were happily born with a natural genius, and our moderns, who being instructed in the principles of the mathematics, have truly laboured very hard to make a progress in the art of shipbuilding, one may, without violating the truth, affirm that the greatest part satisfy themselves with copying such ships as they esteem good sailers, and it is these servile mechanick methods, which, to the great reproach of the art, are but too common, that have produced all these pretended rules of proportion, all these methods of describing the midship frame, and forming the rest of the timbers, which every builder endeavours if possible to conceal, and keep wholly in his own family.

How low and mean is this? it is as if a great architect should endeavour to conceal the proportions of the different orders of architecture; whereas they are published every where, and so well known that many can raise a very beautiful porch or triumphal arch; but tho' the methods of describing the midship frame, and forming the rest of the timbers, be known to most apprentices, yet we have but few good master builders: This requires more than those mechanick rules; they should at least have such a knowledge of the mathematicks, physicks, mechanicks, of the nature of solids and fluids, as to be able to discover what figure would procure some good quality, without hazarding or putting a bad one in its place.

Let us suppose one to have a collection of draughts of a vast number of ships, and whose good and bad qualities have been remarked with all possible exactness, such a valuable treasure would be of great service to a person who could calculate precisely by the draughts where the fault lay, and how it might be rectified. For instance, suppose a ship sails well, but carries her guns too low, a builder who is not acquainted with these principles would raise her deck, in consequence of which she would not sail well; whereas, one that could exactly calculate how much the resistance of the fluid is diminished upon the prow, would take great care
to

to add no more to any of the other parts than he could find by an exact calculation might be done without augmenting the resistance in the fluids.

M. Bouguer has published several useful problems for making these calculations, to which we refer the reader, and only explain what regards the height of the gun deck, and the resistance of the fluid, in one example of a 70 gun ship.

CH A P. VIII.

To know by the Draught how high a Ship will carry her Guns out of the Water.

THIS is only to know if, when a ship is loaded with all her ammunitions and provisions on board, and ready to sail, her seat in the water will then agree exactly with the load water line in the draught.

It may be demonstrated by several experiments, that any floating body of whatsoever figure will just sink so far in the water as to displace a bulk of water of equal weight with itself.

Hence it will be necessary, first to find a method of calculating the exact weight of a ship ready equipt for sea, and secondly, to know the exact weight of the water the ship displaces, when loaded to the water line in the draught.

In order to the first, the exact weight of all the timber, iron, lead, masts, sails, rigging, and in short of all the materials, men, provisions, and every thing else on board the ship must be known.

It must be confessed that this is a very laborious task, yet the zeal of our modern builders has surmounted all these difficulties, and got the exact weight of a ship of each class, with all its furniture, and six months provisions on board. It will be sufficient for our purpose to give the particulars, of the two following, one of 30 and another of 50 guns, both ready equipt for sea, with six months provisions on board.

An Estimate of the Weight of the RENOMEE Frigate of Thirty Guns, with Six Months Provisions.

WEIGHT of the HULL.

	Cubic feet	Under water Pounds	Above water Pounds.	Total Tons Pounds	
Oak timb-ber { under w. at 72 lb. per f. above w. at 66 lb.	5640 2920	406080	192720	299	800
Fir at 50 lb. per foot { under water above water	600 560	30000	28000	29	000
Carved work			2200	1	200
Iron knees and standards		4200	7010	5	1210
Bolts, rudder irons, chain plates, nails		11650	6558	9	208
Lead for the haufe holes & scuppers		250	430	0	680
Locks			170	0	170
Oakum		1200	1830	1	1030
Pitch and Tar			650	0	650
Paint			440	0	440
In the Cook room			8000	4	000
Total		453380	248008	350	1388

WEIGHT of the FURNITURE.

	Under W. Pounds.	Above W. Pounds.	Total Tons Pds	
Masts compleat set and spare	3000	37000	20	00
Blocks	1000	5444	2	444
Pumps	1734	670	1	404
Cables and Hawfers	24444		12	444
Sails and their Cafes	4222	3778	4	000
Anchors and their Stocks	2611	6944	4	1555
Cordage for the rigging		17282	8	1282
The master's Stores	3333		1	1333
Boats		6666	3	666
Total	40344	75784	58	128

WEIGHT of the PROVISIONS, &c.

	Under water. Pounds.	Above water Pounds.	Total Tons Pounds	
Provisions for 6 months for 200 men with all their equipage	245420		122	1420
Water for two months and a half	100000		50	000
Casks	32800		16	800
The Captain's table	15000	5000	10	000
Total	393220	5000	199	220

WEIGHT of the OFFICERS STORES.

	Under water Pounds.	Above water Pounds.	Total	
			Tons	Pds
The Carpenter's Stores	3000	1000	2	00
The Caulker's Stores	1000		0	1000
The Surgeon's Effects	2400		1	400
The Pilot's Effects	740	360	0	1100
The Chaplain's Effects		100	0	100
	7140	1460	4	600

WEIGHT of the GUNS and AMMUNITION.

	Under water Pounds.	Above water Pounds.	Total	
			Tons	Pds
Iron Guns		60300	30	300
Carriages fitted		14000	7	00
Balls round and cross bar	11570	2430	7	00
Balls of one pound	600		0	600
Powder and Powder Barrels	7108	112	3	1220
Implements for the powder	1368	132	0	1500
Crows, Handspikes, Gunners Utensils, and Stores	3200	1500	2	700
Musquets, Cutlasses, and Pole Axes		900	0	900
	23846	79374	51	1240

WEIGHT of the MEN and their EQUIPAGE.

	Under water Pounds.	Above water Pounds.	Total	
			Tons	Pounds
8 principal Officers and their Effects		4000	2	00
200 Men and their Effects		40000	20	00
Total		44000	22	00
BALLAST	200000		100	00

RECAPITULATION.

	Under water Pounds.	Above water Pounds.	Total	
The Hull	453380	248008	350	1388
The Furniture	40344	75784	58	128
The Provisions	393220	5000	199	220
Officers Stores	7140	1460	4	600
Guns and Ammunition	23846	79374	51	1220
Weight of the Men		44000	22	00
Ballast	200000		100	00
Total	1117930	453626	785	1556

An Estimate of the Weight of a Frigate of Fifty Guns, with Six Months Provisions.

	Under water Pounds.	Above water Pounds.	Total	
The Hull	774270	769134	771	1404
The Furniture	98237	163184	130	1421
Ballast	300000		150	000
Guns and Ammunition	679400	199320	133	1280
Provisions	659400	8000	333	1400
Stores	9800	2800	6	600
Men and their Equipage		77000	38	1000
Total	1909667	1219438	1564	1105

But as all ships of the same class are pretty near the same dimensions, and have the same number of guns, &c. we may have the exact weight of each only by examining the draught of water, and computing the weight of that column of water which is displaced by the ship.

Now if the *Intrepide* weighs 2718 tons, she must sink so far into the water till she has displaced a column of water containing $73459 \frac{1}{2}$ cubick feet, for a cubick foot of salt water being supposed to weigh 74 lb. the $73459 \frac{1}{2}$ will weigh 5436000 lb. or 2718 tons, or if she displaces $73459 \frac{1}{2}$ cubick feet of salt water, we may thence conclude that she weighs 2718 tons.

In like manner, if the weight of the ship which is to be laid down in

the

the draught be known; as, for instance, that if a ship of 78 guns, is 2350 tons, we may with certainty know if the water line in the draught be properly placed, only by reducing the bottom into cubick feet.

The antient builders were unacquainted with the manner of performing this, but our moderns make an exact calculation of the contents of the bottom before they begin to build, whereby they will be sure to keep the lower tier of guns well out of the water.

If a ship's body were any regular figure, the solid contents of it could easily be found geometrically, but as the case is quite otherwise, we must be satisfied with dividing it into several parts, of which we may have a great number, and they will thereby become so small, that they may, without any sensible error, be esteemed as regular figures, limited by straight lines, tho' some of them are actually curves.

In the draught of the 70 gun ship which we have laid down, the bottom is divided on the plain of elevation into several parts, in a vertical way, by the lines that represent the frames; and in an horizontal way by the water lines; so that the whole may be said to be divided into so many parallelopipedons, A, B, C, D , or a, b, c, d , contained betwixt the two frames 6 and 7, and limited on the side AB by a plain supposed to be erected vertically upon the keel, and on the other side by the round of the outside of the ship, at the height of the breadth water line, or ac . Now it is very plain that the area of the surface, which limits the lower part of this solid, is less than the area of the surface, which limits the upper part: But if we increase the water lines and frames, we may find the solid contents to a sufficient exactness for our purpose.

Now, in order to find the area of the upper surface $ABCD$, let AC be 16 feet 11 inches, and BD 13 feet 6 inches; add these two, the sum is 30 feet 5 inches, the half of which is 15 feet 2 inches and a half, and this sum multiplied by AB , which suppose 8 feet, the distance betwixt the frames, the product is 121 feet 8 inches, the area of the upper surface of the parallelopipedon.

The area of the lower surface of the parallelopipedon may be found after the same manner, which suppose 97 feet 4 inches. Now, if these two areas be added together, their sum will be 219 feet, the half of which is 109 feet 6 inches for the mean area, and this multiplied by ab , the distance betwixt the water lines, which suppose 4 feet 4 inches, produces 474 feet 6 inches cubick.

By the same process we may find the solid contents of the other parallepipeds, and adding them together, and doubling that sum, we shall have the

the solid content of the whole bottom of the ship in cubick feet to a sufficient degree of exactness.

I made use of this method before M. *Bouguer's* treatise was published, where there is one which is more convenient and expeditious, for, instead of finding the area of every single surface contained betwixt the frames upon the section of a water line, he finds by one operation the area of the whole surface formed by the horizontal section or water line, except that part intercepted betwixt the aftermost frame and the post, and the part contained betwixt the foremost frame and the stem, which, upon account of the rake must be measured seperately, as also all that lies betwixt the upper side of the keel and the first water line. His method is as follows :

Take the lengths of all the lines that represent the frames on the horizontal plane, add all these together, excepting the foremost and aftermost, of which take only one half of each, so if it were required to find the area of the surface formed by a horizontal section in the plane of the load water line, it will be $\frac{1}{2} ZZ + BD + AC + IH + LK, &c. + KS \times AB$, supposing AB to be the distance betwixt the frames equally spaced betwixt ZZ and NO,

To demonstrate this, let it be considered by what operation the two trapezia ABDC and HIAC are measured. We observe in the proceeding article that this was performed by adding the length of the lines BD and AC together, and then taking half that sum ; the length of the lines AC and HI, must likewise be added together, and the half of that sum taken ; now it is evident that it will be the same thing to take half the line BD, and half the line HI, and the whole line AC, and add all these three together, because the line AC, is common to both the trapezia.

After the areas of all the water lines are thus found, the solid content of the space contained betwixt the water lines may be had by multiplying the are. by the distance between the water lines : But, because the areas of the two surfaces which limits this part are unequal, a mean area must be found ; this is half the sum of the two areas, so that all that is now to be done, is to add the areas of the water lines into one sum, excepting that of the uppermost and lowermost, of which only one half of each must be taken, and if this sum is multiplied by the distance betwixt the water lines, the product will give half the solid content of the bottom, observing that the water lines in the plain of elevation be equally distant from one another.

The application of this method in finding the cubick feet contained in a 70 gun ship laid down in the draught.

The

The forepart is divided into eight, and the after into nine equal parts, besides that betwixt the aftermost timber and the post, and that betwixt the foremost timber and the stem.

The bottom is likewise divided into four equal parts by water lines drawn parallel to the load water line, all which are formed upon the horizontal plane; for it will be very useful to know the solid content of each particular part contained betwixt the water lines, also to distinguish that of the fore body from the after body, whereby we may be enabled to know if the weight be duly poised. We shall consider all this in the following calculation.

Note, there must be four inches added to each line that represents the frames in the horizontal plane for the thickness of the plank, that being nearly a mean betwixt the thickness of the plank next the wale, and that next the keel.

The Area of the Upper Water Line abaft.

The breadth of the surface at the load water line, upon the midship frame *a Q* is 21 feet 2 inches,

		feet.	inch.
Breadth at	one half is	10	7
	1st Frame	21	2
	2d Frame	20	11
	3d Frame	20	9
	4th Frame	20	5
	5th Frame	19	11
	6th Frame	18	11
	7th Frame	17	4
	8th Frame	15	7
The 9th Frame <i>X S</i> is 12 feet 9 inches, one half of which is		6	$4\frac{1}{2}$
Total		171	$11\frac{1}{2}$

which total doubled is 343 feet 11 inches, and multiplied by 8, the distance betwixt the frames, is the whole area of the water line, from the midship to the after frame, in cubick feet

To this must be added the area of the trapezium *X S L e*

Now half of the lines *X S* and *L e* is 10 feet 0 inches

Distance betwixt them is

$$\begin{array}{r}
 \text{Product is } \frac{9}{97} \frac{9}{6} \\
 \text{which being doubled is } \frac{195}{2946} \frac{0}{4} \\
 \text{The whole area in cubick feet}
 \end{array}$$

By using the same process, we may find the areas of all the other water lines; and adding all these areas together, excepting that of the first and fifth, of which taking only one half, multiply this sum by 4 feet 5 inches, which

which is the distance betwixt them, we shall have the area in cubick feet of that part of the ship abaft the midship frame, contained betwixt the lower water line, and load water line.

	feet	inch.	l.	p.
Half of the area of the load water line	1473	2	0	0
Whole area of the 4th water line	2516	1	4	0
Whole area of the 3d water line	2052	0	4	0
Whole area of the 2d water line	1452	10	7	6
Half the area of the 1st water line	144	3	2	0
Total	7638	5	5	6
Multiplied by the distance betwixt the water lines	4	5	0	0
Product in cubick feet betwixt the lower and load water line	33736	6	1	3 6
Betwixt the lower water line and keel	333	6	3	0 0
Keel and post	101	8	0	0 0
Cubick ft. abaft the midship frame under water, when loaded	34171	8	4	3 6
Cubick ft. before the midship frame under water, when load.	28928	6	1	0 0
Total cubick feet under water	63100	2	5	3 6
Multiply by the weight of a cubick foot of salt water		pounds.	tons.	lb.
Weight of the whole ship, with all her furniture, provisions, &c.	4661498	2334	1498	

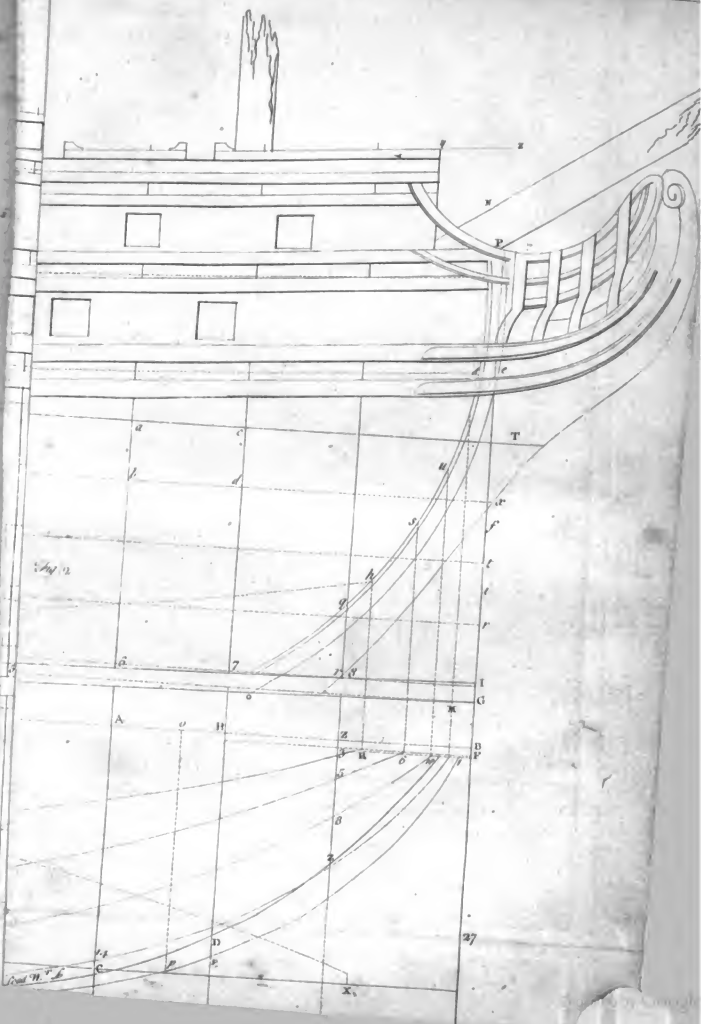
We have omitted the operation for the fore part, because it is performed exactly by the same method with the after part.

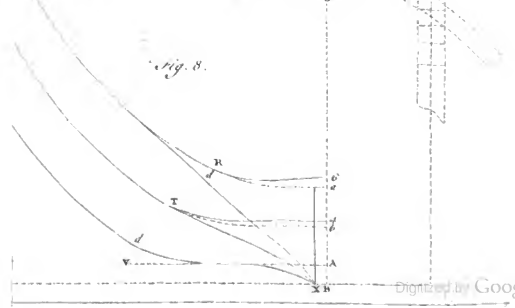
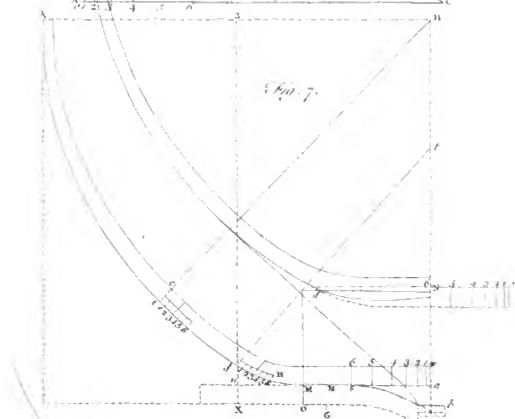
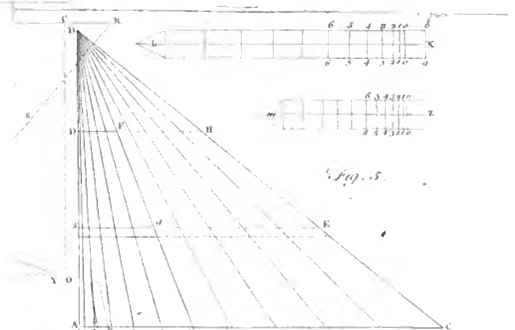
It must be observed, that in finding the cubick feet of that part contained betwixt the lower water line and upper side of the keel, we must take the heights of all the frames intercepted betwixt these two lines, and divide their sum by the number of frames abaft the midship, the quotient will be 1 foot 9 inches 9 lines.

	Feet	In.	Lines
The area of the lower water line is	288	6	4
The area of the upper side of the keel	79	6	0
Total	368	0	4
One half is	184	0	2
Area of that part contained betwixt the lower water line and keel	333	6	3

The use of the preceding calculation is to know if the load water line upon the draught be properly placed.

It has been found that a ship of 70 guns, with every thing on board, should weigh nearly 2350 tons, which is only 15 tons 1297 pound more than what is found by calculating from the load water line in the draught, this difference would occasion the ship not to draw above one inch more
wat





water it is not worth the regarding. But then by this calculation we discover that the ship is too lean before; for whereas the fore part should exceed the after part by 30 tuns, we find, by this calculation, that the after part exceeds the fore part by 193 tuns 1995 pounds.

Upon this account we must consider carefully if the midship frame is properly placed; it is here 5 feet before the middle. If the midship frame was exactly in the middle it would augment the weight of the fore part 102 tuns 307 pounds, and diminish that of the after part exactly the same quantity, by which means the fore part would be 1172 tuns 1014 pounds, and the after part 1162 tuns. Now we may fill out the fore part, so as to gain 15 tuns 636 pounds, which was deficient, to make the calculation taken from the draught agree with the real weight proposed for a ship of 70 guns fitted out for sea, with six months provision on board; and the fore-body will weigh 25 tuns 1255 pounds more than the after part, which may be judged sufficient.

C H A P. IX.

A Method to calculate the Resistance of the Water upon the fore Part of the Ship.

DAILY Experience sufficiently proves that the fluids, by their motion, attack the solids that oppose them, as bridges, mills, &c. with such violence as to carry all before them; and this is agreeable to the very nature of fluids.

For all fluids are an assemblage of a prodigious number of small solid bodies of a globular form, each of which being easily put in motion will act upon any surface with the same force that any other solid body of the like mass would do. But as these particles have but a very small cohesion with each other, fluids cannot act with the same force as solids which have their parts united.

A mass of water of 20 cubical feet will not act with the same force upon the pier of a bridge which opposes it, as a mass of ice of the same dimensions; because the whole mass of ice having its parts so united together, that one cannot advance without the other, it gives the blow with the united force of all the parts at once, whereas the parts that compose the mass of water, being but slightly united, they cannot act jointly or in concert, and they exert their force one after another; they indeed succeed one another immediately, and are a little united by their reciprocal pres-

I

sure;

!

sure; but as every part has its own peculiar velocity, so it makes its effort singly by itself, and, being easily put in motion, it will be as easily turned out of its direction, the parts being only retained together by the weight of those that come next them.

Fluids have a continual effort, because when a certain number have produced their effect they are succeeded by others as long as the current lasts.

Hence it will follow, that when a vessel is left to a current of the river, it can receive no more velocity than the current has, and its velocity will be accelerated till it is equal to that of the current.

If, on the contrary, any floating body receives a motion in a contrary direction to that of the current, it will be continually retarded, till it has none, and then it will change its direction to follow that of the current.

We shall here remark, that it is indifferent whether we ascribe the motion to the solid or to the fluid; for the impression of the water upon the ship's stem is the same when under sail, as when at an anchor, provided the motion of the current be equal to that which the ship acquires by sailing.

The effort of fluids is as the square of the velocity of the current.

It is very plain that the more rapid the current is, the greater will the impression of the fluid be; for the parts will then shock the solid with greater force than when it runs slowly; so that the force is augmented in proportion to the velocity. Again, the number of the parts of the fluid that strike the solid in any space of time, is in proportion to the velocity of the current; for the faster it runs the greater will be the number of the parts that strike the solid in a space of time; so that not only the effort of the fluid, but likewise the number of parts that attack the solid, is augmented in proportion to the velocity of the current, and when these two are united, the effort of the fluid will be in a duplicate ratio of the velocity; so that if the velocity be doubled, the shock will be quadrupled.

Hence, the faster a ship goes through the water, the greater will be the resistance she meets with, and this will be augmented in a duplicate ratio of the velocity with which she sails.

The impression of a fluid increases as the surfaces which oppose its current.

It is very plain, that if one surface is double another it will receive double the number of the parts of the fluid, and of consequence the impression will be double upon the surface, whose area is double the area of another surface. Hence these ships whose midship frames have the greatest capacity meet with most resistance.

The efforts of fluids will be less when the surfaces are in an oblique position to the current, than when in a perpendicular position.

Plate

Plate IV. Fig. 7.] Let $E A$ represent the course of the fluid setting perpendicularly on any body $A B$; it is plain, that it receives the impression of all the parts of the fluid contained between A and B ; whereas, if the point B be moved to D , the parts of the water contained betwixt B and G will have no impression upon $A D$. Hence the quantity of the fluid which attacks $A B$ is to that which attacks $A D$ as $A B$ is to $A G$; that is, as the radius is to the sine of the angle of incidence $E A D$. But if there were no other advantage gained by this oblique position, than being exposed to fewer parts of the fluid, it would be of very little service to a ship which must have a sufficient breadth, suppose $A B$; it is plain, the number of the parts of the fluid which give the impression will be the same, when the fore part of the ship is in the form of $A D B$, as when it is flat in the form of $A B$; but the fluid which exerts its force on the surface $A D B$ does not produce the same impression as when it exerts its force on $A B$, because the direction of each particle of water, which strikes any surface obliquely, may be resolved into two directions, one perpendicular, and the other parallel to the plane.

In order to give us an idea of compound motions, and of the resolution of their forces, let us suppose two rulers $A A$ and $B B$, (*Plate IV. Fig. 5.*) placed upon a plane at right angles to one another, and a small ball C placed at the angle of their meeting, it is plain, if we slide the ruler $B B$ in a parallel position to itself, it will carry the ball C along the edge of the ruler $A A$; but if both the rulers be made to slide together, so that they still preserve the same angle, in such a manner that when the ruler $A A$ arrives at the line VII , VII , the ruler $B B$ arrives only at the line 3 , 3 . It is plain, the ball will describe the diagonal of the parallelogram C , VII , D , 3 . the sides of which will be proportional to the distance the rulers have moved, that is, D , VII is to D , 3 as 3 to 7 ; but if the rulers be supposed to be moved equally, so that when $A A$ arrives at the line VII , VII , $B B$ shall arrive at the line 7 , 7 , the ball will describe the diagonal $C F$ of the square C , VII ; F 7 .

Now, if we substitute any other two agents in the place of the rulers, such as two hammers, and both be supposed to strike the ball with equal force at the same time, it is plain, the ball will go in the direction of the diagonal $C F$; but if the force with which one hammer strikes the ball be to that by which the other hammer strikes the ball, as 7 to 3 , then the ball will move in the direction of the line $C D$.

The principal Effects of Compound Motions. (Plate IV. Fig. 6.)

If two powers C and B act with equal force on the body A, that is to say, that the power C would drive to B in the same time that the power B would drive it to C; in the contrary directions of the lines C A and B A, the body A will remain at rest; but if one of the powers acts with greater force than the other, the body will follow the direction of that which predominates, diminished by the quantity of the smaller force.

2d, If two powers D and E act upon the body A in the same direction, viz. in the lines D A and E A, the body A will follow the direction of both, and pass through the point F, with this only difference, that it will go with greater velocity when impelled by both powers than with one.

3d, Let the two powers G and H strike the solid A, in the direction of the lines G A and H A, it will thereby receive a compound motion, the force and direction of which may be expressed by the diagonal of a parallelogram, as was before observed.

In order to construct this parallelogram, which is called the *resolution* of the forces, let the two powers G and H be supposed equal and expressed by the lines H A and G A; from the point G draw the line E G equal and parallel to H A; from the point H draw the line E H equal and parallel to G A, and the diagonal E A (the result of the two powers represented by the sides of the parallelogram H A and G A) shall express the velocity and direction of the compound motion; the effect of which will be, that the body A will be carried through the point F. But supposing the forces unequal, and let that of H, (Fig. 9.) represented by the line H A, be double that of G, represented by the line R A; then from the point R draw the line R S equal and parallel to H A, which shall express the force and direction of the power H; and from the point H draw the line H S parallel to R A, which will express the force and direction of the power G; the diagonal S A expresses the velocity and direction of the body A, which will pass through the point T, whereas, if the powers were equal, it would pass through the point F.

It may be remarked, that two attractive powers placed at P and Q, would produce the same effect as two impulsive powers at G and H, and that the parallelogram may be constructed on the lines A Q and A P.

C O N S E Q U E N C E S.

1st. The acuter the angle of the direction of the power is, the nearer will they approach to one direction, and act with greater force; so the result of G and H is greater than that of K and I, supposing the powers to be equal.

2d,

2d. The greatest effect of two powers is, when they both act in the same direction, and the least when they act in contrary directions.

3d. When two equal powers act in such a direction that they form an angle of 120 degrees, as AK and AI ; in this and in no other case, the result will be equal to the single force of AI or AK ; it only changes the direction; for when the two powers act jointly, A will be carried to F , whereas if K only acted, it would be carried to T ; or if I only acted, A would be carried to V ; if L only acts it will be carried to V ; if M only acts it will be carried to T .

4th. If the direction of two powers make an angle less than 120 degrees, as GA and HA , they will assist one another; but if they form an angle greater than 120 degrees, as LA and AM , they will be reciprocally diminished.

The Results of a Motion impressed upon a Body A, in Relation to a Surface a b, which opposes its Motion. (Plate IV. Fig. 6.)

1st. When a body strikes a surface obliquely it will be with less force than when it strikes it perpendicularly; for it may strike it so obliquely as only to graze along it; between the perpendicular shock, which is the greatest, and the oblique, which approaches nearest to a parallel to the surface, there may be an infinite number of directions, less or more oblique, and the surface will be struck with more or less force.

2d. If the two powers are united in D , they will act, in the direction DF , with great force upon $a b$, because they not only act jointly, but likewise in a perpendicular direction upon the surface $a b$.

3d. If the two powers be equal in force, and act in the direction of the lines GA and HA , the body A will also fall perpendicularly on the surface $a b$, but with less force than in the first case, because of the obliquity of the directions.

4th. If the power H have double the force of the power G , then the direction will be changed into the line SA , (Fig. 9.) and the body will strike the surface obliquely in the direction of the line ST , but with less force than in the second case, not only on account of the diminution of the force of the power G , but also on account of the obliquity of the shock.

5th. It will be indifferent whether the body A receives its impulse from one single power, or from two, so that it strikes the surface $a b$ in the same direction. Hence we shall have no occasion to consider the powers which give the motion, but only the velocity and the direction in which they strike the surface.

6th. It will produce the same effect, whether we change the line of direction

direction, in which the body A strikes the surface $a b$, or change the position of the surface $a b$ in respect of the line of direction.

From what has been said, it will follow, that if the common effect of two powers acting upon the same body be known, and also the direction and force of one of them, then the direction and force of the other may be found; for let the body C (*Fig. 5.*) be carried to the point D by the action of two powers, and one represented by the line C, VII; draw the line D 3 equal and parallel to C, VII, and compleat the parallelogram, so shall C 3 express the force of the other power.

The Application of what has been said to the Shock of Fluids.

We have hitherto considered the shock of a solid body in different directions upon the surface of another solid, but we will readily grant that fluids do not act in the shock in the same manner that solids do. It is very probable, that when a fluid falls perpendicularly upon a surface, there is a mass of water that rests immoveable before the surface, which occupies the place of a solid body, and has nearly the same effect as if the surface was round, so that the fluid does not attack the body that opposes it in a direction perpendicular to its course; besides, the particles of water which attack a surface, whether obliquely or not, may rebound and change their direction, so that the laws of fluids are quite different from the laws of solids in the shock.

The oblique direction of a particle of water may be resolved into one that is perpendicular to the body which opposes its courses, and one that is parallel to it.

In order to construct this resolution, (*Plate IV. Fig. 11.*) upon the line A C inclined to the current, form the parallelogram A H E F (A E representing the velocity and direction of the current) making E F parallel to C A and E H perpendicular to C A. The diagonal E A, which represents a particle of water and its velocity, will be the result of a motion supposed to be produced by two powers, one parallel to A C, whose force and direction is represented by E F, the side of the parallelogram, and the other perpendicular to it represented by the side E H.

Hence it will follow, that when a surface is exposed to the shock of a current, in different oblique directions, the force of the direct shock is to that of the oblique, as the square of the radius is to the square of the sine of the oblique angle of incidence; for the effort of the particle E A, (which strikes the body A B, in a perpendicular direction,) is to the effort of the same particle E A; (which strikes the body A C in an oblique direction,)

as EA is to EH ; but EA is to EH as AB , the sine of the right angle, is to AG , the sine of the oblique angle of incidence. But it was before observed, that the sum of the particles that strike AB is to the sum of the particles that strike AC as the radius is to the sine of the angle of incidence. Hence, by multiplying the effort of one particle, by the number of particles that strike AB , (that is, the effort of the whole water upon AB) and multiplying the effort of one particle by the number of particles that fall upon AC , that is, the effort of the whole fluid upon CA) we shall have the following proportion: The effort of the whole fluid upon AB is to its effort upon AC , as the square of the radius is to the square of the sine of the angle of incidence.

When the surfaces AB and AD , which oppose the current AE , are unequal (*Plate IV. Fig. 10.*) the quantities of water which strike these surfaces are as the product of the surfaces by the sines of the angles of incidence; from whence we shall have the following proportion: The effort of the fluid upon AD is to that upon AB , as the square of AG , the sine of the angle of incidence multiplied by the surface AD , is to the square of AB , the radius, multiplied by the surface AB .

CONSEQUENCES.

1st. If two equal surfaces, exposed to the same current, receive its shock in different obliquities, the impressions will be to one another as the squares of the sines of the angle of incidence.

2d. A surface parallel to the current can receive no shock, because there is no angle of incidence.

3d. If two unequal surfaces are exposed to the same current, the impressions they receive by the shock in different obliquities, are to one another as the products of the squares of the sines of the angles of incidence, and of the surfaces that receive the shock.

4th. If two equal surfaces receive the shock of two unequal currents, the impressions will be to one another as the products of the squares of the velocities, and of the squares of the angles of incidence.

5th. If two unequal surfaces are exposed to two unequal currents, which strike them with different obliquities, the impressions will be to one another as the products of the squares of their velocities; of the squares of the sines; of the angles of incidence; and of the surfaces.

All these consequences may be deduced from the preceding principles; it only remains to apply them

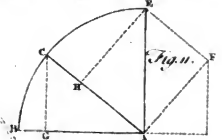
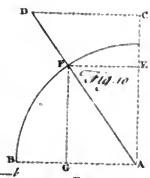
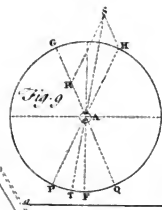
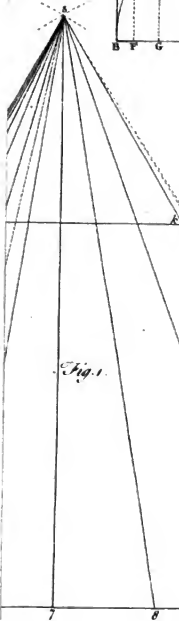
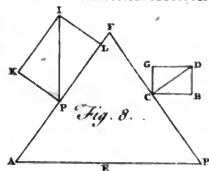
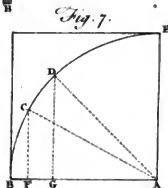
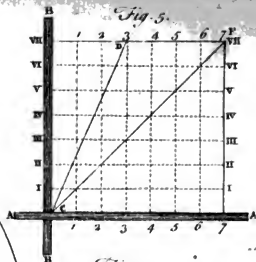
Let AB (*Plate IV. Fig. 4.*) represent the extreme breadth of a vessel, and let the fore part be formed according to the angles ACB ,

or

or AFB , or ALB . In order to find the efforts of the fluid, supposing the velocity and direction to be the same, and parallel to the keel, in the three cases, upon the middle of the line AB , erect the perpendicular EL , which will pass through the tops of all the triangles; then to find the sines of the angles of incidence, with the radius AB describe two arches, AF and BF , to intersect one another in the vertex of the equilateral triangle; the arches will intersect the sides of the angle, that is less than 60 degrees; but not the sides of that which is more than 60 degrees; produce one of the sides from C to M (*Plate IV. Fig. 4.*) Lastly, let fall the perpendiculars MD , FE , PK , upon the line AB , from all the points where the arches intersect either the sides of the triangles, or the sides that are produced; so shall AE , AD , and AK , represent the sines of the angles of incidence upon the different triangles AFB , ACB , and ALB .

It will be easy to observe, that the effort of the fluid upon the intire fore parts ACB , AFB , or ALB , is to the effort upon the extreme breadth, as the effort upon AC , AF , or AL , is to the effort upon AE ; but it was proved before, that the impressions received by two unequal surfaces, opposed to the direction of a current, are as the squares of the sines of the angles of incidence multiplied by the surfaces; so, in this case, the impression on AC will be to that on AE , (or, which is the same thing, the impression on ACB will be to that on AB) as the square of AD , the sine of the angle of incidence, multiplied by ACB , is to the square of the radius multiplied by AB .

We have also the effort on AFB to the effort on AB ; as AFB , multiplied by the square of AE , the sine of the angle of incidence, is to AB , multiplied by the square of AB the radius. This proportion would shew the effort of the fluid upon the prow AFB , in a perpendicular direction to the sides AF and BF , which would be very useful, if it were required to determine the dimensions of the timber that is to resist that pressure of water; but in the present case, where only the relative effort upon the prow is considered in the direction of the keel, we must form another resolution. Let then CD (*Fig. 8.*) represent the effort upon FB , perpendicular to that surface; if from the point D we let fall the perpendicular DH , and complete the parallelogram $GCDH$, CG shall represent the relative effort upon the prow in the direction of the keel, so the whole effort upon FB , may be represented by FB multiplied by the square of the angle of incidence, which is to the relative effort as FB is to EB : The relative effort then is equal to the square of the sine of the angle of incidence multiplied by EB , or by the sum of the particles which fall upon FB ; so to find the relative effort on FB , we must multiply



multiply the square of the angle of incidence by the projection of the plane FB upon the beam EB .

Tho' this method cannot be truly applied but to rectilineal triangles, yet, by dividing curves into a number of small parts, each may be considered, without any sensible error, as a strait line. *M. Bouguer* makes use of this method of approximation to a sufficient degree of exactness. What we have already said upon that head, it is to be hoped, will facilitate this description to such as have only a slight knowledge of the mathematics; so that all that remains now is, to apply this to the draught of a ship of 70 guns, which has been already laid down.

A Calculation of the Resistance of a Fluid upon the Prow of a Ship of 70 Guns, which we have laid down in a Draught, compared with the Effort of the same Fluid upon the Area of the Midship Frame.

As the operations are to be performed upon the plane of projection before laid down, all the frames in the fore part must be exactly formed as before in *Plate II.* in order to which it will be necessary to make use of a larger scale, as in *Plate V.*

It will be very convenient to draw the water lines $I, II, III, \&c.$ and the frames $1, 2, 3, \&c.$ to the midship frame, at equal distances from one another.

It is plain, that the water lines and frames divide the prow into trapezia, such as $ra, 8b, 7c, \&c.$ corresponding to the trapezium AD , and parallelogram ad , in the plane of elevation, *Plate II.*

It will be necessary to observe, that there must be so many water lines and frames, that the lines $8a, 7b, 6c, \&c.$ which are curves, may be esteemed strait lines.

We must draw the diagonals $ra, 8b, 7c, \&c.$ through the trapezia; but we may take two trapezia at once near to the midships, because the ships sides are there nearly parallel to the current.

It will likewise be proper to observe, that these diagonals are the projections of the diagonals of the parallelograms represented upon the plane of elevation, at least, on the surface of the ship; as for instance, the diagonal $8b$, on the plane of the projection, is the projection of the diagonal $8d$ drawn on the plane of elevation.

These diagonals divide the prow into the triangles $1, 2, 3, 4, \&c.$ which strike the fluid with different degrees of obliquity.

We have not the entire areas of these triangles, by reason of the curving of the prow, but only their projection on the midship frame; but this is all we want; for the sum of all the particles of water that strike the tri-

K

angles

angles are proportioned to the triangle projected on the midship frame, since the water that ranges along each triangle may be considered as a triangular prism, the base of which is equal to the triangle $r a 8$, Fig. 1. Plate V. and this was the thing in question. M. Bouguer proposes to calculate the effort of the fluid on each triangle, their sum will give the shock of the water upon the whole prow, and compare this to the shock of the fluid upon a surface parallel to the area of the midship frame.

To attain this, M. Bouguer lets fall perpendiculars to every frame, from the angles formed at the intersection of the water lines and the diagonals that were drawn to form the triangle; for instance, upon the frame 8, the perpendiculars $l b$ and $r p$; upon the frame 7 8, the perpendicular $8 m$ on one side, and the perpendicular $n c$ on the other side, &c.

This method requires that there be as many right angled triangles formed as there are triangles on the prow; and as there must be a great number of them, it will be necessary to find some method of forming them. The following seems to me to be the most expeditious.

Draw two parallel lines, B D and C R; let the distance betwixt them be equal to that betwixt the frames on the plane of elevation, and by this one operation we have the height of all the triangles that are contained betwixt the parallels.

As the base of all the rectangles should be equal to the perpendicular of the corresponding triangle of the prow, we may set off the length of each perpendicular upon the parallel C R; so shall C H, Fig. 2, be equal to $r p$, Fig. 1; H L, Fig. 2, equal to $s a$, Fig. 1; L E equal to 8 M, &c. To compleat the triangles, draw the perpendiculars H N, L M, and the hypotenuses D H, N L, &c.

If one of these rectangles be considered singly, D H may represent the radius, and C H will be the sine of the angle of incidence.

All these triangles being described, we may begin to find their areas on the plane of the projection, because it is upon this that the relative impulse in the direction of the keel depends; which is the thing now required, as was before observed.

The surface of a triangle is found by multiplying half the base by the perpendicular; so the surface of the triangle $r, a, 8$, will be the product of the perpendicular $r p$, (equal to C H) multiplied by half the base $a 8$, and this will be the sum of all the particles which strike the triangle $r, a, 8$, which is an element of the prow of the ship.

In order to find the relative force of the fluid in the direction of the keel on that part of the bottom corresponding to the triangle $r, a, 8$, it is only

only multiplying the surface of the triangle by the square of the sine of the incidence; in place of multiplying it by the square of the radius, which would give the impulse the triangle would receive from the water in a perpendicular direction; now if we divide this impulse by the oblique one, the quotient will give the quantity that the impulse is diminished by the obliquity of the prow; but there will be no occasion for this last step, for as the sum of all the products of the triangles multiplied by the square of the radius, gives the effort of the fluid upon the midship frame; the direct effort may be found by multiplying the area of the midship frame by the square of the radius, and if this be divided by the sum of the products of all the triangles, multiplied by the squares of the sines of the angles of incidence on each triangle, we shall know the diminution of the resistance which the prow meets with in proportion to that of the midship frame.

It would be almost impracticable to multiply the surface of each triangle by the square of the sine of the angle of incidence, upon which account *M. Bouguer* substituted proportional lines in place of the squares of the sines, which we shall now explain.

It was before observed, that if DH be the radius, CH will be the sine of the angle of incidence.

If we let fall the perpendicular CO upon the line DH , we shall have the triangle DCH similar to DOC ; so taking the equal lines CD , and NH for the radius, CO will be the sine of the angle of incidence.

If we draw OP perpendicular to DC , the triangles DOC and COP will be similar, therefore the triangles DCH and COP will be similar, and DH is to CH as OC to CP ; but DH is to CH as DC to CO , and by multiplying these two proportions, the square of DH will be to the square CH as DC is to PC ; that is, if DC represent the square of the radius, PC will be the square of the sine of the angle of incidence CDH . So the lines CP , HQ , LG , &c. give the squares of the sines of the angles of incidence in the triangles 1, 2, 3, &c. which are to be multiplied by the surfaces of the triangles; and the parallels DC , NH , &c. always represent the radius.

A Calculation of the Resistance of the Fluid upon the Prow of a Ship of 70 Guns, compared with that upon the Midship Frame.

Triangles.	Perpendicular.	Multiply- ed by half the base.	Product.	Multiply- ed by the square of the sine of the angle of incidence.	Product gives the effort of the water up- on the trian- gle.
ft.	f. in. lin.	f. in. lin.	f. in. lin. poi.	f. in. lin.	f. in. lin. poi.
1	6 6 0	1 9 6	11 7 9 0	3 2 0	36 10 6 6
2	5 7 6	1 6 3	8 6 7 10	2 8 0	22 9 9 0
3	4 6 6	1 9 6	8 1 7 9	1 11 6	15 11 2 8
4	4 6 6	1 9 6	8 1 7 9	1 11 6	15 11 2 8
5	2 9 6	1 8 6	4 9 2 9	0 11 0	4 4 5 6
6	2 8 0	1 9 6	4 9 4 0	0 9 0	3 7 0 0
7	1 11 6	1 7 6	3 2 2 3	0 5 0	1 3 10 11
8	2 2 0	1 9 0	3 9 6 0	0 6 6	2 0 7 9
9	1 4 0	1 7 6	2 2 0 0	0 2 6	0 5 5 0
10	1 4 0	1 7 6	2 2 0 0	0 2 6	0 5 5 0
11	0 5 0	1 6 6	0 7 8 6	0 1 0	0 0 7 8
12	0 10 0	1 7 6	1 4 3 0	0 2 0	0 2 8 6
13	0 2 6	1 6 6	0 3 10 3	0 0 8	0 0 2 6
14	0 4 0	1 6 6	0 6 2 0	0 1 2	0 0 7 2
15	0 1 0	1 6 6	0 1 6 6	0 0 3	0 0 0 4
16	0 5 0	1 6 6	0 7 8 6	0 1 6	0 0 11 6

The total effort of the first piece r V

Of the second

Of the third

Of the fourth

Of the fifth

Of the sixth

104 2 8 8

57 10 6 2

43 8 6 5

28 0 8 10

12 9 8 7

3 2 8 11

Total 249 10 11 7

We must in the next place find the direct effort of the water upon the area of the midship frame, by multiplying the area by the square of the radius.

O P E-

O P E R A T I O N.

Half the 6th water line r VI	10	2	0
The whole 5th water line V.	20	0	0
The 4th water line	19	5	0
The 3d water line	18	1	0
The 2d water line	15	11	6
The 1st water line	12	0	0
The breadth of the keel	0	0	0
Total	95	9	6
Multiplied by the distance betwixt the water lines, which is	3	2	0
Product is the area of the midship frame	303	4	1
Multiplied by the distance betwixt the frames	8	0	0
Product	2426	8	8

This being divided by $249 : 10 : 11$, the sum of the efforts of the fluid upon the triangles of the prow; the quotient is $9 \frac{1}{10}$, which shews that the effort of the fluid upon the prow is to that upon the midship frame as 1 is to $9 \frac{1}{10}$, which is a sufficient diminution of the resistance for a ship of this force. Hence we may conclude that the water lines in the fore-body are well formed, but a frigate will require more diminution, as will appear by the following examples.

The *Brillant*, as $3 \frac{1}{2}$ to 1, a very bad sailer.

The *Tigre*, as 5 to 1, a company keeper.

A ship of 50 guns, designed by M. *Boyer*, but not built, as 8 to 1.

The *Monarque*, of 74 guns, 4 lb. shot, built by M. *Ollivier* in 1744, as $13 \frac{1}{2}$ to 1.

The *Alcide*, of 64 guns, by M. *Ollivier*, at Brest 1741, as $6 \frac{1}{2}$ to 1.

The *Renomme*, built at Brest by M. *Desalieux* 1744, as 10 to 1.—This ship, by the account of the captain, was a very fine sailer.

The *Badine*, 6 guns of 3 lb. shot, as $7 \frac{1}{2}$ to 1.

The *Panthere*, of 20 guns 6 lb. shot, as $10 \frac{1}{2}$ to 1.

The *Amazon*, of 44 guns, built by M. *Blaise Pengalot*, as $8 \frac{1}{2}$ to 1.

The *Superbe*, built by M. *Helie*, as $5 \frac{1}{10}$ to 1.

The *Mutine*, of 24 guns, built by M. *Geffroi*, senior, as $10 \frac{1}{2}$ to 1.

We have compared the efforts of the fluid upon the prow of each ship, with that upon the plane, equal to the area of the midship frame.

It will be proper also to examine if the resistance in those be less than in ships which are known to be good sailers; but it may happen that a

L

ship,

ship, whose midship frame has a small area, may meet with little resistance, tho' her prow be not diminished in proportion to that of her midship frame; so it will not be sufficient to know this proportion only, to be assured whether or not the ship will be a fine sailer. We must also compare the areas of the midship frames, and not rest satisfied with comparing the efforts of the fluid, upon the prow of the ship we have laid down, with that upon the prow of the ship of the same rate, which has gained a good character.

The first Example of Comparison.

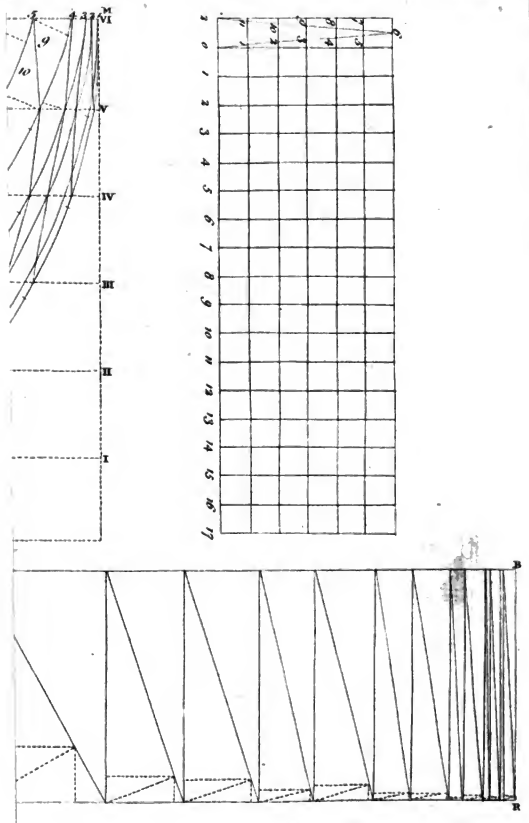
We know that the area of the midship frame of the 70 gun ship, we have laid down, is 606 : 8 : 2, and that the effort of the fluid upon the prow is to that on the midship frame as 1 is to 9 $\frac{7}{10}$. Now if another ship of the same rate has the area of her midship frame 7 or 800 feet, supposing the sails, and every thing that may contribute to sailing, to be alike in both; its plain this last cannot sail so well as that we have laid down, and by this example, it is very plain, that if we would calculate which of two ships would sail best, we must, after finding how much the resistance of the fluid upon the midship frame of each is diminished by the form of their prows; also compare the areas of their midship frames, that we may know which of the two has the greatest mass of water to displace; but if it was only required to know, which of two ships of the same rate would sail best, it would be sufficient to compare the efforts of fluids upon their prows.

The second Example of Comparison.

We have found by the calculation, that the effort of the fluid upon the prow of our ship of 70 guns, is 249 : 10 : 11 : 7; but if, by a like calculation, we find the resistance upon the prow of a ship of the same force, and carrying the same quantity of sail, to be 300 feet, we may thence conclude that ours will sail best.

It will also be proper to examine, by the same calculation, whether the ship we have laid down, can carry a good sail, drive but little to the leeward, and steer well.

F I N I S.



S U P P L E M E N T

TO THE

TREATISE ON SHIP-BUILDING.

CONTAINING

E X T R A C T S

TRANSLATED FROM

M. BOUGUER's *Traité du Navire.*

TOGETHER WITH

M. DUHAMEL's Method of finding the Center of Gravity.

And some Occasional R E M A R K S.

A L S O

An Account of several E X P E R I M E N T S, made to ascertain
the F O R M of a S O L I D that will move with the greatest
Velocity through the Water.

L I K E W I S E

A Method to determine the Thickness of the Plank, in the Direction of
the Planes of the Timbers.

With the Proportions for MASTS, YARDS, CAPS, &c.

By M U N G O M U R R A Y.

L O N D O N :

Printed for A. MILLAR, in the *Strand*.
MDCC LXV.

P R E F A C E.

IN grateful acknowledgment to the public, for their favourable reception of my first Edition, I have, in this Supplement, collected all the discoveries I could either make by my own observations, or gather from the writings of M. BOUGUER and M. DUHAMEL.

I have likewise endeavoured to determine the thickness of the plank in the direction of the planes of the timbers, and have illustrated it with a Plate engraved for that purpose ; Plate V. in the first edition, being too much crowded with lines, to admit of any addition.

Also an account of experiments that have been made to ascertain the form of a solid that will move through the water with the greatest velocity. These experiments likewise serve to determine the properest position of the midship frame.

The proportions for masts and yards, caps, tops, trussel-trees, and cross-trees, are inserted.

Likewise the weights of the anchors, the dimensions of the cables, the number, nature, length, and weight of the guns on each deck, according to the rates of the several ships in his Majesty's Navy.

C O N-

C O N T E N T S.

Of the Progress of Ship-building in France.

Capacity and Velocity, two essential qualities for floating vessels that are built for carrying goods from one place to another Page 1

An enquiry into the properest form of such vessels.

<i>The cylindrical tub considered</i>	—	—	ibid.
<i>The cube</i>	}	—	2
<i>The parallelopiped</i>			
<i>The wedge</i>			
<i>Of towing a mast butt-end foremost</i>	—	—	4
<i>The necessary data to determine the whole form of a ship</i>	—	—	5

Extracts from M. BOUGUER's *Traité du Navire*.

<i>The division of his treatise, with his remarks on the form which the common rules give to ships, and by what methods they may be amended</i>	9
<i>His method of forming the ship by two demi-cones</i>	14
<i>Of the cables in France</i>	17
<i>Of anchors, with an explanation of M. Bouguer's method of finding the weight of an anchor</i>	18
<i>Proportions of masts in France</i>	23
<i>— of yards</i>	24
<i>His remarks and experiments on the dimensions of masts and yards</i>	25
<i>His account of an experiment on a model at Havre de Grace</i>	30
<i>His account of the solid of least resistance; that is, such as is not liable to be broke in one part more than another</i>	32
<i>His mechanic way of finding the center of gravity</i>	34
<i>Improvements on M. Bouguer's method of finding the center of gravity by a block</i>	35
<i>Of finding the center of gravity of the whole ship, when properly loaded, by a block</i>	36
<i>A general rule for determining the tonnage of ships taken into his majesty's service</i>	38

M. Bou-

<i>M. Bouguer's method of finding, by a simple experiment, if the center of a ship be properly situated, even after she is built</i>	39
<i>He mentions some chimerical causes, on which it is imagined a ship's sailing depends</i>	43
<i>He considers the measure of the absolute shock of the water, and of the wind</i>	44
<i>His description of the anemometer</i>	46
<i>He considers the impulsion of fluids on different fluids</i>	47
<i>the impulsion of fluids in respect of the axis</i>	48
<i>Remarks on M. Bouguer's method of finding the sines of the angle of incidence, and how it may be found by trigonometry</i>	49
<i>He considers the velocity of the ship's sailing, in proportion to the velocity of the wind</i>	52
<i>And the effort of the wind on the sails</i>	53
<i>Remarks on the changes which, he says, the motion of the ship will produce on the force and apparent direction of the wind</i>	54
<i>He considers the situation and number of masts</i>	55
<i>The figure a ship should have, in order to make her steer perfectly well with her sails</i>	57
<i>He endeavours to determine the exact point where the extreme breadth should be placed, to render the ship more sensible of the power of the helm</i>	58
<i>Remarks on the contents of his eight chapters in his 4th section</i>	59
<i>His tables of dimensions for forming several sorts of bows</i>	62
N. B. Fig. 67. represents the curve formed by the first table.	
<i>His conclusion</i>	65
<i>Abridgment of what M. Duhamel has said on the center of gravity</i>	67
<i>Of what M. Duhamel says of the ballance</i>	ibid.
<i>His method of finding the center of gravity of lines and surfaces</i>	68
<i>Of solids</i>	69
<i>Of solids whose parts are of unequal weights</i>	70
<i>His definition and application of mometa</i>	74
<i>His method to find the center of gravity of a ship</i>	78
<i>Of the pressure of fluids</i>	82
<i>He considers, that the builders may vary the form of the ship in three dimensions, viz. length, breadth, and thickness</i>	88
<i>Of the friction, or lateral pressure of the water</i>	93
	T ₂

<i>To bevel the cant-timbers by diagonal ribbands</i>	-	Page 100
<i>To find the thickness of the plank in the direction of the plane of the timbers</i>	- - - - -	103

Dimensions of the Masts and Yards.

<i>Extreme breadth and length of the gun-deck of thirteen merchant ships</i>	106
<i>A ready way of making a beam mould</i>	109
<i>Proportions for the length of masts and yards in the royal navy</i>	111
<i>---And for their diameters at the partners or flings</i>	112
<i>---For their diameters at the quarters</i>	113
<i>Explanation of the way of notation in the proportions, and the solution by the sliding-rule</i>	ibid.
<i>Proportions for the beads and bounds of masts, caps, tops, and trussel-trees</i>	115
<i>Proportions for cross-trees, weight of anchors, and dimensions of cables</i>	116
<i>A Table of the number of guns on each deck, their length, weight of metal, and of shot</i>	117

S U P P L E M E N T

TO THE

PRACTICAL TREATISE

O N

S H I P - B U I L D I N G .

M. BOUGUER, in the Preface to his *TRAITE DU NAVIRE*, gives an account of the progress of ship-building in *France*, with the names of several eminent men who applied themselves, with much zeal, to reduce naval architecture to certain mathematical principles; and says, that at a conference held at *Paris* in 1681, the principal dimensions used in *France* were established by an order of the arsenal. He makes mention of *Pierre Janſſe Horn*, who, in the beginning of the last century, imagined that *Noah's* ark should be made the standard and pattern of the form of a ship: But *M. Bouguer* observes, he did not consider that the ark, far from being designed to sail with any degree of velocity, was built only to sustain a great weight, when lying at rest on the surface of the waters of the deluge. Be that as it will, it seems, at least probable, that the first design of building floating vessels, was to carry goods from one place to another.

Now, the properest vessels for that purpose would be such as could contain the greatest quantity of goods, and carry them in the shortest time to the intended port: So that capacity and velocity seem to be two essential qualifications.

As to the first, that of capacity, a circle has a greater area than any other plain surface of the same circumference; and, consequently, a cylindrical tub would be the properest form to answer the first end, but the very worst for the second, *viz.* that of velocity: For, by what method soever the power that sets the vessel in motion is to be applied, it is indifferent what point goes foremost; and if it were applied in an opposite direction, the

Supp.

A

vessel

vessel would go as fast a-stern as a-head, if I may be allowed that expression, where there is neither head nor stern.

A Cube is the next solid of greatest capacity ; but this is subject to the same inconveniencies as the Cylinder : Hence we may conclude, that all floating vessels may be longer than broad.

An oblong rectangular parallelopiped will go with greater velocity endways than sideways ; but it will be indifferent which end goes foremost ; and, besides, this form would meet with great resistance in passing through the water. For, let the component parts of that fluid be supposed never so small particles of a globular form, it is certain they must have some kind of cohesion ; and tho' they are easily set in motion, they must actually be separated before any body can pass through them ; and any plane moving in a direction perpendicular to itself, must displace as many of these particles as are contained in the area of that plane ; and, as it advances forwards, will still have the same number of particles to displace, before it can go a-head ; hence we may conclude, the parallelopiped will not answer the two essential properties.

Let us next examine, how far the wedge would answer those purposes : This being tapered to an edge at the fore-end, will easily divide the fluid, and the sides will attack the particles in an oblique direction, and consequently will meet with less resistance in passing through the water. If the particles of water were as closely united as those of wood, perhaps the wedge would be the properest form to force its way through a body of water. But it must be observed, that the wedge acts in a quite different manner, when cleaving a tree, and when dividing a fluid ; for the parts that unite the tree are separated at a great distance before the wedge, and the parts through which it has passed are so far from endeavouring to unite themselves again, that the extremity of the tree will be double its diameter asunder, before the wedge has advanced near the other end ; whereas, the wedge has no sooner passed through the particles of water, but they immediately unite as close as before, and none of the particles are separated till the wedge actually strikes them, and no sooner has the wedge forced its way through any number, but it has the same number to encounter, and drags a quantity of what is called dead water after it : for, placing a flat piece of wood in the water, at the after end of the wedge, it will keep close to it, till the wedge alters its direction ; for which reason, there seems to be a necessity for tapering the after-end of the wedge. It must likewise be observed, that the mall that forces the wedge a-head drives it in a direction perpendicular to the after-end ; whereas the wind that forces a ship a-head, sometimes strikes it in a direction

direction oblique to the keel, which will be apt to drive it out of the direction of the keel, as is the case of a ship that loses her rudder: This is another reason for tapering a ship at the after-end, for otherwise the rudder would have but very little power to keep her steady in a strait course.

We have now found, that all ships must be longer than they are broad, and likewise tapered at each end: The next thing to be considered is, whether or no the sides should be perpendicular to the bottom: In that case, all vertical sections perpendicular to the keel, and at right angles, would be parallelograms, which would be a very improper form for dividing a fluid; for though, by the tapering at the fore end, the resistance would be lessened, yet the particles should be so far separated as to allow the plane of the midship frame to pass through them; and though the effort of the fluid upon the midship frame would be greatly diminished by its oblique direction, yet as the ship would then be as broad at the keel as at the water's edge, the bow would meet with great resistance every time the ship went about; so that there seems to be a necessity, not only of tapering them at each end, but likewise from the extreme breadth down to the keel.

The next enquiry must be, whether these vertical sections are to be limited with curve or strait lines, and how to ascertain their form.

The mathematicians have endeavoured to investigate the form of that solid which meets with least resistance in passing through the water; but they have not drawn any practicable rules from thence, to determine the form of a ship; and should they be so lucky, after a tedious calculation, as to find out the particular form of such a solid, it would be of little use in forming the body of a ship: For it is supposed, that the solid is to continue in the same position in the water, otherwise the immersed part will alter its form as often as it alters its position, unless it be, as *M. Bouguer* would have it, formed by the revolution of a curve round its axis. Hence we may conclude, that the particular form of a ship cannot be determined by rules that will admit of a mathematical demonstration.

The builders, finding they could have very little assistance from the mathematicians, have applied themselves to experience; and though they have not found any particular form which may be a standard for all ships of the same burthen, and designed for the same service, yet in some points they seem to agree. Hence it is, that, in ships of war, of the same rate, the principal dimensions are nearly the same; and in all ships the midship frame is nearer the fore-part than the after-part. For,

finding by repeated trials, that a mast or tree, when tapered, will tow faster through the water with the butt end foremost than with the small end, they conclude it will be so in ships; though M. *Buguer* thinks the only reason for towing the butt end foremost is, that the rope may not slip. The rules given us by M. *Buguer*, for calculating the resistance, seem to be deduced from the same principles as those for ascertaining what weight will raise any heavy body on an inclined plane, which may be effected with as great certainty as by weights in a pair of scales, as is proved by experiments.

If the particles that compose a mass of fluid were solids of such a particular quality, that when once separated, they could not be united again, without the application of some exterior force, the same rules might answer in both cases. But when it is considered that the particles of the fluid have a natural energy, whereby they unite themselves as soon as the force that separated them is removed, we may hence conclude that every particle has two motions, the one parallel, and the other perpendicular to the axis of the mast. If the mast were at an anchor, floating on the water, and a current setting parallel to its axis, the shock sustained by the mast would be the same as if the mast were in motion, (with a velocity equal to that of the current) and the current at rest. It seems probable, that the natural tendency the particles have to unite themselves, will as it were grasp the mast, and retard its motion, when the small end is foremost; whereas, when the butt end is foremost, and hath once opened a passage, the particles, by their union, will rather force it a-head, or at least prevent its going a-stern; and experience seems to favour these principles; otherwise a ship would go fastest stern foremost. M. *Buguer* tells us, the reason for making ships fuller before than abaft, is, not to make them go with greater velocity through the water; for, he says, that would have a quite contrary effect, but to make them steer well.

Since capacity is an essential quality, the immersed part must be of such a form as to be able to sustain the whole weight of the ship completely rigged, with guns, ammunition, provisions, stores, &c. The weight of all ships of war, of every rate, is now pretty well known; so that we may find, by calculation, if the load-water line be properly placed: But this is not all that is to be considered; great regard must be had to the velocity, stability, property of steering well, carrying sail, and many other necessary and seemingly opposite qualities. How to attain all these qualities has been attempted by several eminent mathematicians and builders, who, instead of determining any particular form, have

have produced as many different, and seemingly directly contrary rules; as there are different complexions and statures among the projectors.

The mathematicians have given certain rules for finding the center of gravity, both of the ship when properly loaded, and also the center of gravity of the column of water she displaces, M. *Bouguer* likewise gives directions how to stow the goods, so that the center of gravity may be properly placed with respect to the *metacenter* and the center of gravity of the column of displaced water; which last cannot be altered after the ship is built. It is on the proper situation of these that the stability of the ship depends. As to velocity, they have given us rules for calculating the resistance of the fluid on the fore part of the ship: but unless it can be proved that the velocities are always proportional to the resistances, it seems we shall gain little by this; as there is no account taken of the after body, and in the calculations they suppose the ship to be upright, and sailing in the direction of the keel; whereas a ship often lays her scuppers in the water, when close hauled on a wind, and sometimes makes two or three points lee way, seldom less than one; and yet some ships in smooth water will then sail within two or three knots as fast as when going large. We may venture to assert, there will be no proportion betwixt the velocities, and resistances in these two cases; for in the first all the particles that strike the fore part lose their power as soon as they pass the midship frame; afterwards, according to his principles, they occasion no resistance; whereas, in the second, every particle has its full force, acting on the whole length of the side, and the area of the section, which in this last case would receive the perpendicular shock, would be almost double that of the midship frame; add to all this that there is room to suspect these rules of being deduced from wrong principles, as was before observed. But admitting all this, and that the velocities may be calculated, after the ship is built, and found even by experience to be proportionate to the resistances, what will that avail us, if we have no instructions how to form the body so, as to be capable of the greatest velocity, in all positions, consistent with the requisite capacity, stability, &c? There are other very material points to be considered, such as the center of rotation, or the axis on which the ship turns when she inclines to one side, when she tacks or pitches; these are continually shifting, as is the point of sustentation or suspension.

In all branches of the mathematical sciences, there are certain theorems demonstrated, from whence the practical rules for the solution of various problems are deduced, in which there are always some necessary data given, by which the unknown things may be discovered.

It

It is to be wished we could proceed in the same manner, and with the same certainty, in ship-building ; but I do not find that any who have treated that subject have given us any invariable rules for settling these points ; and indeed, considering the infinite number of properties, and in some cases so opposite to one another, that if any of them be pursued to too great a degree, it will destroy another very essential quality. I say considering all these things, it will be a very difficult task, if not impossible, to unite them all in one body ; add to this that the different seas, and different services in which they are to be employed, will require as different forms ; so that theory alone, without actual experiment, seems insufficient to reduce this complicated art to a regular system. I shall just mention some of the necessary *data*.

1st. The whole weight of the ship compleatly rigged and boarded.

This is generally given, both in ships of war, and in those for the merchant service, being what is generally understood by tons ; that is, builder's tons ; but the true tunnage of most ships of war is now pretty well known, as the number and weight of the guns, provisions, &c. of each rate is established.

2d. The length of the gun deck.

This in ships of war may be nearly determined by the number of guns.

3d. The breadth.

If the section of the load-water line were a regular curve, the length would determine this, and its area might be calculated ; and converting the whole weight into cubick feet of salt water, and dividing those by the area of the load-water line, we should have the depth or draught of water ; that is, supposing the form of the body to be that of a bathing tub, which perhaps would be very proper for carrying goods in a canal, where it might be dragged by horses ; but as ships are to encounter high seas, and sustain the violence of storms of wind, it is plain they will require a quite different form.

4th. The depth of the hold, and draught of the water fore and aft.

5th. The extreme breadth of three sections at right angles to the keel, and perpendicular to the plain of flotation ; and likewise the extreme heights of these breadths, together with the breadths and heights of the top-timbers of these sections ; one of them to be near the middle, another at the after end of the keel, and the third at the beak head.

6th. The rake of the post and stem.

7th. The situation and exact form of the midship frame and likewise of the other two vertical sections ; and if to these three we add the other

two

two which M. *Dubamel* calls the balance frames we may safely say the whole form of the ship is determined.

The great difficulty will be to obtain these *data*. M. *Bougner*, and after him M. *Dubamel*, hath pursued this subject as far as the nature of theory is capable; from whence they have deduced several useful practical inferences, but have still left these points undetermined, and at last refer us to the general practice of the most experienced builders. So that what improvements have been hitherto made seem chiefly owing to experience; and some think it highly probable that the form which comes nearest nature, such as that of the swiftest fishes, will best answer the purposes of shipping. But here we shall find ourselves very much embarrassed; for fishes are wholly immersed, and the force that moves them is wholly in their own power, and they are in no danger of being drove out of their intended course by an external force, the author of nature having furnished them with every thing that is necessary, either for pursuing their prey in a direct course, or turning themselves as occasion requires; whereas in a ship, it is quite otherwise, as she is entirely subject to an external force, and governed by the helm; and therefore her form must be such as may be most capable of receiving these impressions, and what nature has denied her, must be supplied by art.

As all who have written on this subject have left these points undetermined, I shall not attempt it. I have in the appendix to the first edition abridged the substance of what M. *Dubamel* has said in his treatise, and in this Supplement shall extract some of M. *Bougner*'s fundamental principles, together with what M. *Dubamel* has advanced on the center of gravity in his second edition; which I shall endeavour to translate so as to be intelligible to those who do not understand the *French* language, and, as occasion offers, make such remarks of my own as I think necessary.

EXTRACTS

E X T R A C T S

F R O M

M. BOUGUER's *Traité du Navire*.

M. BOUGUER divides his Treatise into three books, the first of which contains a general idea of the construction of ships, and divers remarks on the common rules, in three sections.

In the first section, which he divides into twelve chapters, he defines the names of the different pieces that form a ship, and their proportions, according to the practice of the most eminent builders; and likewise describes the various methods used by them in forming the timbers. This takes up the first nine chapters; for which we refer to M. *Dubamel*, who has given us the substance of what M. *Bouguer* has said on those heads, as translated in the Appendix.

In the 10th and 11th chapters, M. *Bouguer* makes some remarks on the form which the common rules gives to a ship, and by what methods they may be amended.

It would be needless, says he, to give any further account of the several methods used by builders to form the figure of their ships, and project the frames; but it seems that all these prove, beyond dispute, that they have not yet found out a fixed rule. The only reason why they have used so many different methods, is, because they could not find the best. It would have tended much more to the advantage of their art, if they had in practice kept by one general rule, and only changed some particular circumstances, carefully remarking the result of such a change.

Experience would have proved the best means of bringing naval architecture to perfection, if the thing had been possible; but it is plain, that practice alone is insufficient in many cases; for, though some points may be determined thereby, yet, with respect to many others, it stands in need of theory. As nothing but a sincere desire of finding the truth, has engaged us in these researches, we shall not fail to take proper notice of what is good in the common rules, and shall support them by all the arguments that may occur to us. I imagine the midship frame might

Supp.

B

be

be carried further forward, and placed, not at $\frac{1}{11}$ of the keel, but at $\frac{1}{11}$ of the length of the immersed part, or even a little nearer the head. Thus it would always be nearer the fore part than the after part; the fore part would be fuller than the after part, and the immersed part would have more of the form of a fish.

It is well known, that the extreme breadth of every frame is higher abaft and afore than in the midships, but more on the aft part, which will make the ship draw more water abaft than afore, about one sixth part of the depth of the hold. As the fore part cannot so readily divide the water, when the keel is perfectly level, as when it is inclined to the stern, it being uncertain what property to ascribe to it, the most eligible method would, doubtless, be to try the result at sea, and make choice of what experience indicates.

Seamen, no doubt, tried to find her best sailing trim when at sea; and having frequently remarked, that it was necessary to make her draw more water abaft than before, they established it as a law, by observing it; whereby we shall at least gain this advantage, that the ship will answer her helm better. This will occasion the decks not to lie parallel to the keel; for, admitting they may be of the same height afore, that they are in midships, they are raised considerably higher at the post, about the sixth part of the depth of the hold.

Now, taking what we have said for granted, the builders, after all their trials, are very far from having found out the true figure of the bow, from whence almost the whole of the round should be taken away.

The decks being fixed will determine the height of the beams; so the decks will be no where so high as the extreme breadth of the frames, but in midships. There is another important reason for raising the breadth higher afore than abaft, though few attend to it. When a ship is close hauled by the wind, and lays much over the weather side, it will lose much of the breadth; whereas, on the contrary, the lee side will gain considerably. The ship then displaces a great deal more water on the lee side, and, according to the manner in which fluids act, should be supported with greater force, and of consequence be able to carry the greater sail. Hence it is plain, that, by raising the breadths, we keep them as a reserve, to be used when the ship stands most in need of relief; that is, when she lays most over. It may be remarked, that the flat floored ships have least need of raising the breadths; for, carrying all the weight of their cargo so low, they are thereby capable of carrying a great deal of sail. Though we cannot absolutely condemn the practice of making

making a ship draw more water abaft than afore, yet we cannot approve of any of the rules that the builders have given us to determine the exact difference. A ship may be built to a precise draught of water, by which the construction will be founded on true principles; but when a ship is not built to one precise draught more than another, which is the case of most of the ships that have hitherto been built, it will be very difficult, and one of the most complex questions in naval architecture to determine this precise point: One would imagine there is no more to be done but to make the ship swim in the water, so as to be capable of carrying the greatest sail; but when a ship is very deep in the water, this will greatly increase the resistance, and of consequence be very prejudicial to her sailing. We need not absolutely find that part which will meet with least resistance: When a ship has but little hold in the water, she can carry but little sail, and therefore cannot go so fast through the water. The resistance then must be calculated, not absolutely, but relatively, in proportion to the canals she spreads. This will be a most laborious and tedious calculation, as not only the various and irregular curves which compose the body must be nicely examined, to ascertain the resistance in different draughts of water, but likewise the weights of every part in the ship, and in what manner they are stowed; all these must be given before we can determine; in every case, the power that will be sufficient to sustain the force of the wind; on which account, it will be proper to advise the mariners to make frequent experiments of the ship's seat in the water; for the solution of this problem is only an approximation, even when the minutest circumstances are considered. It is true, some builders, who would not be stoppt by any difficulties, even such as puzzle the greatest mathematicians, have imagined they could find out this by another method. Many of them pretend to examine the difference of the draught of water when the ship is launched, and would have it to be the same when the ship is loaded; our readers cannot but pity us, to be obliged seriously to confute these and such parallel maxims. If a ship sails best when loaded to the proposed load-water line, she cannot sail so fast when she draws only one half, or one third part of it: So there can be no manner of proportion between a ship's draught of water, when launched and when loaded: And this method proposed so mysteriously to us by the *gens du metier*, and received with too much respect by many mariners, serves only to confirm us in our opinion, that very little regard should be had to all their other rules.

But if these common maxims are found so imperfect, it must be owing chiefly to the figure they give their ships; for it is impossible to

discover, by practice alone, and by experiments, though never so often repeated, all the properties of an entire surface, which is an assemblage of an infinite number of curve lines and points. There can then be no manner of doubt but it is in this very article the art stands most in need of amendment. In general, the fore part is too full, and on that account the ribbands that form it are too round. The mariners are very sensible that part should not be too sharp, but they have not adverted that it will be sufficient for that purpose to carry the midship frame further forward. It may be, that, considering all these particulars, we cannot always rigorously follow the precepts of theory, but it will at least be of great advantage to know them, that we may have the point of perfection always in view, even when we cannot arrive at it, but are obliged to stop short of it.

If the floor ribbands were formed only by narrowing the breadths of the frames, without any rising, and terminating the fore part at the extremity of the keel, this would occasion the ribbands to be perfect strait lines; by this means, the foremost frame would be a rectangle, and the bow formed by two vertical planes intersecting one another in a vertical ridge at the extremity of the fore part, where they would form an acute angle. *Fig. 1.* represents such a bow, wherein the ribbands CA, FD, cannot fail of being strait lines.

But if we give a rising to the frames, and cut off the bow by the fore part of the keel, as in *Fig. 2.* the ridge AD, or common section of the two vertical planes, would run so far below it, as is DF, the whole quantity of the rising, and so the bow could not be formed by plain surfaces; the ribbands would become curves, and the more so, by raising the point D, or augmenting the rising DF: At the same time that the figure would be more advantageous, it would approach the nearer to a *maximum maximumum*, in which resides the highest point of perfection. In such a case, the fore part would be the figure of a regular demi-conoid; its base, instead of being circular, would be a rectangle.

But what is principally worthy of our notice, is, that, according to the common dimensions of ships, it always happens, that when the rising is the greatest possible, and that all the vertical ridges at the extremity are vanished, and the fore part has by that means acquired the most advantageous figure of any, the ribbands also, having acquired their greatest curvings, will round no more than the arch of a circle of 18 or 20 degrees; or, which is the same thing, they differ so little from a strait line, that the round in the middle is but the twentieth, or the two and twentieth part of the whole length. Now, taking all this for granted; the builders,

builders, after all their trials, are very far from having found out the true figure of the bow, which they have been obliged to make almost strait; so far they are from knowing that rule, which would be so very useful to them, and which they may regard as the secret of their art; namely, that the less the rising $F D$ (*Fig. 2.*) is, or the lower they carry it on the frames afore, so much the straiter will they make all the ribbands $C A$, $E D$, &c.

What we have advanced here depends on a very complicated theory; one may be very easily deceived, seeing the two points which limit the curve are so very near one another, that they will make the ribbands quite strait, as in *Fig. 1*, or give them scarce the round of an arch of a circle of 13 or 20 degrees, as in *Fig. 2*; they will acquire this last by increasing the height of the rising line afore; whereas, by diminishing the rising, the ribbands will come nearly strait. We may, by a diligent attention to this single maxim, without adhering strictly to speculative rules, reap the fruit of the whole; we may keep the form of the midship frame, but we shall gain much by making the extreme breadth no more than the fifth or sixth part of the length, if at the same time we diminish the depth proportionally. This we shall clearly demonstrate, in another place, and likewise this most surprising circumstance, that by diminishing these two dimensions, or by increasing the length, a ship may be made to go some times as fast as the wind.

Let us now again return to the ribbands, which may be equally spaced on the stem, and likewise on the midship frame, from the head of the floor: It will suffice to make them round no more than the twenty-fifth or thirtieth part of their whole length, whether we make them arches of circles, or ellipses, and then there is nothing to hinder them from being formed in the same manner they use to make a fair curve.

By this means it will be easy to give the bow nearly what figure we please. After having formed the midship frame $A D 2 A$, *Fig. 3*, and projected the ribbands $A W$, $G Z$, &c. take the length of one of these, for instance, if $W A$, the breadth ribband, make the strait line $W A$ (*Fig. 4.*) equal thereto, and at the end of it W , draw the perpendicular $W v$, which may be made equal to $W A$, as the point v may be assumed at pleasure, and draw the line $v A$, on the middle of which erect the perpendicular $B C$, which must be the 25th or 30th part of the line $v A$, when that happens to be the length of the ribband, but when it is shorter, as in this case, where it is only the projection of it, $B C$ must be the 10th or 12th part of it. Then describe an arch of a circle thro' the three points A , C , v ; and dividing the line $W v$ into as many equal parts as there

there are to be frames before the midship; draw lines thro' the several divisions D, E, G, &c. parallel to W A, to intersect the arch ν A. These transferred to the line W A, will space the frames properly upon the ribband projected in *Fig. 3*, and will become an arch of an ellipsis, which will have but a very small curving; after the same manner the other ribbands may be divided; it must only be observed that by reason of the rake of the stem the breadth ribband will be longer than the rest; their lengths must not be represented by the line W ν but by a shorter R Q. In order to ascertain this length, suppose of the first intermediate ribband of which S F is the projection, in *Fig. 3*; if it happens that R A is equal to S F it is only transferring the lines R 1, R 2, R 3, &c. to the projection of the ribband, which will give the proper spacings of the frames, but in general produce the line ν W, and from any point K, taken at pleasure, draw strait lines to the points 1, 2, 3, &c. these lines will divide the line S F proportionally to R A; and by this method we may form as many frames as we please. Instead of erecting the perpendicular on the middle of the line ν A, *Fig. 4*, we may have it at the third part of it, making A B double of B ν ; the curve A C ν must then be formed by two arches of different circles whose centers must be in the line C B produced, by using the same process; in all other circumstances we shall imitate that curve which is properest for dividing a fluid.

The after part may be formed by much the same method; the ribbands should be almost strait, not rounding in the middle above the 25th or 30th part of their whole length; thus the whole ship will be nearly the form of two demi-cones, as in *Fig. 5*, whose bases unite at the midship frame, which separates the fore from the after part, and should be placed as was before observed, at $\frac{1}{3}$ of the whole length from the point B, the extremity of the fore part, whereas the general practice is to preserve the whole body, or a considerable space, nearly of the same bulk, and at the same time it will be as fastened to the keel. Although the part A F G, which extends at such a distance beyond the keel, may appear to be useless, yet it cannot be wholly retrenched, because of necessity the rudder must be fastened to the stern post G A. As to the part B C F, it might in a great measure be taken away, if it could be done without prejudice to the fastening of the members together, which is so requisite in forming the body, and were there not another very important reason for not retrenching it, and that is because this will conduce very much to her keeping a good wind, when plying to windward: It is true it will be a great disadvantage to her in wearing, and make her very subject to broach too,

too, but to remedy this we need only give her the more head sail, so that we may without any inconveniency unite all these advantages.

It must be remarked, that when such a ship is formed so as to sail on an even keel, we shall gain nothing by making her draw more water abaft than afore, the resistance which the fore part meets with in dividing the fluid is lessened very little, or scarce perceptible; on the other hand, the rudder cannot fail of producing its effect, because the water will easily strike it with its whole force. When a ship goes on an even keel, there is nothing to hinder us from laying the decks parallel to the keel, it is likewise plain there will be no occasion for laying the wing transom so high, it will be sufficient to make it higher than the depth of the hold, about the eight or ninth part of that depth.

All that we have said belongs chiefly to frigates, that are built on purpose for sailing, without regarding their capacity for carrying heavy goods. But when this is required or when it is necessary to have several decks, and to carry guns, &c. we then form the bow according to *Fig. 6*. At the same time we make the whole immersed part fuller, which will contribute much to prevent her pitching. *Fig. 6* is only a sketch to represent things in general; the builders no doubt can reconcile all the angles, and breaches, or ridges of this figure: If we give the bow as much rising as possible, all the curves which end at the extremity *A*, will then become arches of circles, of 18 or 20 degrees; but in diminishing the rising, and making the ribband *ED* horizontal, that will become quite strait; the other ribbands as *CM* will likewise become strait and parallel to the first, for the whole space intercepted betwixt the planes *BFE C*, and *NDM*. But the rake of the stem, together with the inclination of the sides of the foremost frame *BFE C*, will occasion the upper ribbands to be curves; the surface *DMCE* will be a plane, if the side *EC* of the midship frame be a strait line; whereas because *EC* is commonly a curve it will become cylindric, and in every case *DM* will be perfectly equal to *EC*. When the flat *EF* of the midship frame is half the extreme breadth, the half breadth *LM*, which is equal to *HC*, will be half of *GC*; so the breadth *NM* of the bow, above *D*, at the extremity of the keel, will be equal to *BC*, half the extreme breadth. It will be needless to insist on the manner of describing the frames; it is plain that each of them, as *PRST*, will be formed by two parts perfectly equal to those *BFK*, and *HEC* of the first, but they approach to one another. The distance *RS*, at which they must be placed, will be the flat of each floor or frame, and that flat will diminish in proportion to the distance from *D*, the extremity of the keel. In regard to the part *ANMD*, it may be
formed.

formed by producing each ribband, as CM, by an arch of a circle AMCM, a strait part of the ribband being a tangent to it in the point M; this will occasion the whole ribband CMA to be rounder, which will be more so if we make the flat FE of the midship frame less, since HC becomes greater, and LM is equal to HC. This bow, whether we imitate it only in the principal particulars, or conform to the whole, will meet with greater resistance in passing thro' the water than that shewn before: But the great breadths which are carried high, from BIC, the first section, to the height above the extremity of the keel, will at least make them more capable of sustaining the weight of the sails. This form will make the ship more capable of resisting the violent pitchings, occasioned by the seas striking one end of the ship, which lifts it up, the other end at the same time being plunged into the water, continues to sink till it is stopped by the resistance of the water, or by the weight of that column of water it displaces. Sometimes the ship is not shocked; it is only the sea that looses its horizontal position by the agitation of the surf or waves; the sea all of a sudden withdraws itself from the bow, or from the buttock, which of necessity will occasion that part of the ship to fall down till it find a support: These violent motions may occasion the carrying away of the masts, and will always be prejudicial to her sailing. It is plain there can be no way of preventing, or even diminishing these accidents, but by making them fuller both afore and abaft; we must have recourse to experience to form the ship suitable to the particular service she is designed for; but it is always to be remembered, and it is demonstrable, that when we have only velocity in view, and are to sail in smooth water, as in the *Mediterranean*, with fine weather, the form of the ship should differ very little from two cones joined together by their bases. In short, if the ship is not full enough for the purpose, we may continue the whole breadth for a considerable space; the fifth, fourth, or at most the third part of the whole length, and then form the fore part by the preceding rules. It seems to me, that when we have got a sufficient capacity in the hold, we should raise the floor ribbands afore; otherwise, the bow would too much obstruct her sailing. This last property is chiefly to be observed in ships of war, where the breadth is continued strait but a small space. If, instead of such a vessel as is commonly built for a transport ship, we should build a fly-boat; we need only take for a model the figure of a rectangled paralleliped, and form the fore and aft part by two inclined planes, giving the stem and post a rake. We must be always careful to preserve the two parts represented by BCF, and FGA, *Fig. 5.*

As

As to the rake, if the whole length of the ship be 144, the rake of the stem may be about 44, and when the breadth is continued for a good space it may be 32, and 68 for the rake of the stern post. That form of a fly-boat, where we need only round off the corners, will be the most perfect of any; and, besides, as a great part of the side is strait, it will be thereby proper for carrying guns, and fit for a ship of war.

In the twelfth chapter, which concludes the first section, he shews the manner of launching a ship.

In the second section, our author treats of the furniture of a ship; such as the rudder, capstan, and pumps, which takes up the first two chapters. The third chapter is on the cables and anchors.

The cables and anchors, says he, are of indispensable use to hold a ship when in a roadstead, where she is often exposed to all the fury of the wind and the sea. Every ship has at least five or six cables of different dimensions; and to regulate the largest, which is called the master cable; they make its circumference the 24th part of the extreme breadth; or, which is the same thing, one inch to every foot of the half breadth. Suppose a ship to be 48 feet extreme breadth, the master cable should be 24 inches circumference; but if the ship be 20 feet broad, the cable will be 10 inches; and the dimensions of the other cables will be less, and is always estimated by their circumferences. In *France*, the length of all cables, whether great or small, is 600 feet, or 120 fathoms; for a fathom is always accounted five feet.

It is necessary to have the cables longer, on which account, they are obliged to splice several to one another's ends; but it will be very difficult to make them longer in one piece; the first threads that form them are of double the length, and more: Those of a cable of 120 fathoms long are 180, so that they loose a third part of their length in twisting them in the manner they do, to make the cable. These threads must be in length and proportion to the proposed length of the cable, the execution of which will be attended with difficulty.

One thing may be remarked, which may serve in all the different sorts; that the weight of one fathom of cordage, in pounds, is nearly the fifth part of the square of its circumference. This rule will always be pretty exact, especially, when there is not too much tar put in the yarns; as for instance, the weight of a fathom of cable of 24 inches, will be found, by multiplying 24 by 24, and dividing the product by 5, to be 115½ pounds, and the whole cable, which is 120 fathoms long, will weigh 13824 pounds. The weight of one fathom of a cable of 10 inches will, by this rule, be 20 pounds; for 20 is the fifth part of 100,

Supp.

C

the

the square of 10; and the weight of the whole cable of consequence will be 2400. The weight of a whole cable may be had at one operation, by multiplying the square of the circumference by 24.

The cables would be useless without the anchors, the form of them is to be seen in *Fig. 7*, which is the properest figure for catching hold, in the sand, or in the mud, in the bottom of the sea. The anchors in *France, England, and Holland*, are of forged iron; but in *Spain* they may be seen of copper, and likewise, in several parts of the *South Sea*.

The part *A D*, is called the shank, at the extremity of which there is a ring *E*; *A B* and *B C*, are the two arms, *K C* and *I B*, the fleucks; the stock *F G*, which is of wood, is fixed at the end of the shank, at right angles to the fleucks; the use of this is to make the anchor fall, so that one of the fleucks will infallibly catch the ground. The two arms generally form the arch of a circle, of which the point *H*, is the center, being three eighths of the shank from the point *A*; and each arm is equal to three eighths of the shank, or to the radius; so that the two arms together make an arch of 120 degrees: The fleucks are half the length of the arms, and their breadths two fifths of the length of the arms. In regard to the thickness they generally make the circumference at the throat *A* of the shank, about the fifth part of its length, and the small end two thirds of the throat; the small end of the arms of the fleucks, three fourths of the circumference of the shank at the throat. These dimensions should be bigger, when the iron is of a bad quality, especially when we use cast, instead of forged iron.

When these dimensions are observed, an anchor of 16 feet 9 inches long, will weigh about 7000 pounds; for the workman making some of these parts not exactly to the dimensions, will cause a considerable difference in the weight: But if all anchors were similar, which they should be, their weights would be in proportion to the cubes of their shanks. There is a ready way to find the weight of any anchor, which is to take the length of the shank in inches, and divide the cube of that by 1160. Suppose the shank 10 feet long, or 120 inches; we are only to divide 1728000, the cube of 120 by 1160, the quotient 1545 will be the weight of that anchor in pounds: But if the weight were given, and the length required, we must multiply the weight by 1160, and the cube root of the product will be the required length in inches.

As our author has given us no reason, why we must take 1160 for a constant divisor, or multiplier; I shall here endeavour to demonstrate it: But, first observe, that if the length of the shank of any anchor be given, and its weight, we may then find the weight of any other anchor, whose

whose length is given; and, consequently, if the weight be given, we may, by the reverse, find the length, since all similar solids are in proportion to the cubes of the similar sides. Now M. *Bouguer* has given us this; for he tells us an anchor of 16 feet 9 inches, that is, 201 inches, weighs 7000 pounds. Hence, we have the following general rule:

Let $a = 201$ inches, the given length; $e = 7000$ the given weight,

$l =$ any other length; $w =$ the required weight, then $a^3 : e :: l^3 : \frac{l^3 e}{a^3}$,

we shall illustrate this by the logarithms. The question he proposes; is, admit the length of the shank 10 feet, what is the weight of the anchor?

The first thing is to find the logarithms of the lengths, and, multiplying that by 3, we have the logarithms of the cubes of the lengths.

$$\begin{array}{ll} a = 201 & 2.303196 \times 3 \text{ is } 6.909588 \\ l = 120 & 2.079181 \times 3 \text{ is } 6.237543 \end{array}$$

Having thus found the logarithms of the lengths, we have the solution by the rule of three, by the logarithms.

$$\begin{array}{r} \text{As } 201 : \\ \text{Is to } 7000 \\ \text{So is } 120 : \\ \hline \text{To } 1489 \end{array} \quad \begin{array}{r} 6.909588 \\ 3.845098 \\ 6.237543 \\ \hline 10.082641 \\ 3.173053 \end{array}$$

Now as the logarithms of the first and second terms are constant numbers, instead of adding the first and second terms, and, from the sum, subtracting the first; we may subtract the difference of the first and second terms, which will likewise be a constant number, and the result will be the same, as by the following operation.

$$\begin{array}{rcl} \text{The first term} & 6.909588 & \text{the third term} \quad 6.237543 \\ \text{the second} & \underline{3.845098} & \text{difference} \quad \underline{3.064490} \\ \text{difference} & 3.064490 & \text{the fourth term} \quad 3.173053 \end{array}$$

The reason of this is very plain, for the sum of the second and third terms is .082641, now out of this we are to subtract the first term 6.909588; which may be done, by first subtracting 3.845098; and again, subtract from that remainder, 3.064490: Since these two numbers make 6.909588 the first term, which is the whole number to be subtracted; and if we do not add the second term to the third, we have only the third term left, which is 6.237543; and if from this, we subtract the constant difference 3.064490, we in effect subtract 6.909588, from

10.082641, so the result must be the same, as by the common rule, and this accounts for making 1160 a constant number: For 3.064490, is the logarithm of 1160; which, by an error in the press, is in the original 3.0644580.

We may by the same principles, make a general rule for finding the weight of any shot, whole diameter is given; but we must first find the weight of one shot by a pair of scales. A shot of four inches diameter, is supposed to weigh nine pounds; therefore, as the cube of 4 is to 9, so is the cube of the diameter of any other shot to its weight.

The cube of 4 is 64; its logarithm is 1.806180; the logarithm of 9 is 0.954242; their difference is 0.851938. Hence, we have the following general rule. From the logarithm of the cube of the diameter, subtract the constant logarithm 0.851938, the remainder will be the logarithm of the weight.

Example. Let the diameter be 8 inches; required the weight?

8	0.903090
	<u>3</u>
cube	2.709270
constant log.	<u>0.851938</u>
required weight 72	1.857332

This rule may be applied to gauging of similar vessels, or finding the weight of similar solids, which will always be in proportion to the cubes of their diameters, or lengths, or any other similar dimensions.

But if the solids be of equal lengths, and differ only in their bases, as is the case of cables; their weights will be in proportion to the areas of their bases, or, which is the same thing, to the squares of their circumferences; as, for instance, if a ten inch cable weigh 20 hundred weight; what will a cable of 5 inches weigh?

As 100 the square of 10	2.
Is to 25 the square of 5	1.397940
So is 20 hund. wt.	<u>1.301030</u>
To 5 hund. wt. the required wt.	0.698970

It is upon this principle the rope table is constructed, which is on some pocket rules.

To return to our author: These operations, says he, may be done with greater ease by the logarithms, only taking three times, the logarithm of the length of the shank in inches, and from thence, subtracting the constant logarithm of 1160, which is 3.0644580, the remainder will

will be the logarithm of the weight of the anchor in pounds ; but if, on the other hand, the weight be given in pounds, we need only add the logarithm of the weight to the constant number 3.0644580 ; and, dividing this sum by 3, we shall have the logarithm of the required length.

The smallest ships have five or six anchors, and the greatest generally eight. The mariners have different rules for determining the weight of the anchors ; and, on account of the conveniency of working the ship, they have established it as a rule, that the biggest anchor, or, in their terms, the master anchor, should be three eighths of the beam.

Another rule, but which does not agree with the first, as we shall presently shew, is to make it weigh half the cable ; so a first rate, which is 48 feet broad, and whose cable is 24 inches circumference, weighs 13824 ; her master anchor should weigh 6912 pounds, and the other anchors should be half the weight of their respective cables. The smallest anchor is the cadge, or stream-anchor ; in ships of the first class it should weigh 2300 pounds, and the length be about 11 feet 7 inches. When the length of the anchors is three eighths of the beam, as in large ships, the weight of the anchor will be in proportion to the solidity of the ships, supposing them to be similar ; and, if the ship be twice as broad, the anchor will be eight times more weight ; but, according to the second rule, the weight of the anchor should be half the weight of the cable, and the weight of the cable is in proportion to the square of the breadth ; since it is only the circumference of the cables that differ in great and small ships, the length being always 120 fathoms in all ships. When the ship is double the breadth, the weight of the cable will then be four times more ; and of consequence the weight of the anchor, which is in proportion to that of the cable, will be half the weight it would be by the first rule ; that is, in proportion to the beam.

Although the second rule makes the anchors a great deal lighter, yet we may conform to it, because that will be sufficient when it fails in good ground ; but when the ground is soft and ouzie, the mariners make use of several expedients to succour the anchor ; but the best of all is, and which is chiefly practised, to splice several cables at one another's end ; so they will rub on the ground, on account of their weight ; and by this means, the effort of the ship, on the anchor, will be diminished.

A ship seldom anchors in above 40 fathoms depth, and then it will be very proper to have two cables at one another's ends ; for, if there is but one, the lower part of it will scarce bear on the ground, and the anchor will be obliged to sustain all the shocks and jerks of the ship, which will come quite home to the anchor ; it will not pull it quite out of the ground,

ground, but drag it, in the sea term ; so the ship will drive, and be in danger of being lost on the first rocks. *Fig. 8*, makes this very plain ; *A D* is the anchor, at the bottom of the sea ; *D M N* is the cable, by which the ship rides, of which we have here only represented the bow ; *N* the haufe-hole, thro' which the cable passes, between the two lower decks ; The rope *A B*, fastened to the cross, or throat of the shank, is called the buoy-rope, which sometimes serves to weigh the anchor ; this, in the sea term, is called, weighing it by the hour ; *s* is the buoy, which serves to know where the anchor lies. It is very plain, that, if the length of the cable be doubled, or trippled, the anchor will be dragged horizontally, and with a great deal less force ; for its effort will be diminished by the whole power of the friction of the part *D M* on the ground.

A second advantage is, that by having several cables at one another's ends, they will be less liable to breaking ; for all the parts, lying more upon a level, they will oppose the shocks of the sea in a more perpendicular direction to the motions which the ship receives ; whereas, when the cable is not so long, it will be nearly vertical to the anchor, and therefore cannot bear such a strain : Let the space *L O* represent the force with which the ship endeavours to recoil ; and having compleated the rectangle *L O P Q*, *L P*, the part of the cable which is the diagonal, represents the effort which the cable should sustain, which is greater than *O L* ; and the more it approaches to be vertical, the more it is augmented, though *O L* continues the same.

It is plain, then, that a shorter cable is charged with a greater effort, and should therefore be stronger, otherwise it will only bear the same strain in the proper direction, and will not be sufficient, in an horizontal direction, which is that in which the ship endeavours to drive : It is true, the horizontal effort *O L* is all that is to be resisted ; but then the cable, being inclined, cannot resist this, without being furnished with a force sufficient to sustain the whole effort *P L*.

The long cable will not be so apt to break as the short one, because it will bear a great deal more stretching, before it comes to the greatest strain ; so that, at the first violent tugg, because it will not bear stretching, it must infallibly break.

A long cable may be compared to a sort of spring, which may be very easily extended ; and recovers its first situation, as soon as the force that extended it is removed. Besides all this, a ship will ride much smoother with a long cable than with a short one, and be less apt to plunge in the water ; whereas, as the mariners have too often experienced, when

when a ship rides with a short cable, she frequently pitches all the fore part under water.

The fourth chapter is on the power and action of oars; and, in the fifth chapter, he gives the following proportions for masts and yards.

All ships have generally four standing masts; the first is the main-mast, which stands in the middle of the ship: The second is the fore-mast, which is pretty near the fore end of the keel; this is nearly as long as the main-mast: The third is the bowsprit, which, instead of standing upright, stives forward, and rests on the head of the stem: The fourth is the mizen-mast; but some small ships have not this mast; it stands abaft, towards the poop. Besides these, the main and fore masts have top and top-gallant masts, and the mizen-mast a topmast. All these masts have their particular sails, and are named according to their respective masts.

The main-mast is placed in the middle of the ship, measured from the head of the stem to that of the post, or its whole diameter abaft the middle of the ship: All the builders agree in this, but they differ widely as to the rest; some place the fore-mast precisely at the fore end of the keel; others again take the 40th or 50th part of the whole length, from the stern, for its place; and some will have it stand on the stem. The bowsprit generally stives, so as to make an angle of 35 degrees with an horizontal line. Lastly, the mizen-mast is about three sixteenths of the length of the whole ship, before the head of the stern post: If the ship be 160 feet long, the mizen-mast is 30 feet before the stern post.

In *France*, the main-mast is generally, in length, twice the breadth and half the breadth of the ship; whereas, the *English* make it only twice the breadth and two fifth parts of the breadth; so, supposing the ship to be 40 feet broad, the *French* builders would make the main-mast 100 feet long, whereas the *English* make it only 96.

The *Dutch* make their masts somewhat longer than ours, though they agree with all other nations in regulating the lengths of their masts by the breadth of the ship. The head of the mast is always the tenth part of the length of the mast.

The diameter of the main-mast, at the partners, is as many inches as three fourths of the extreme breadth is feet; so, if the extreme breadth be 40 feet, the main-mast will be 100, and the diameter, at the partners, 30 feet, that being three fourths of 40; or, which is the same thing, the 40th part of the whole length of a ship supposed to be 160 feet: The diameter at the head is generally allowed to be two thirds of that at the partners, which will make it 20 inches.

I must own, says our author, it is with violence to myself that I
am

am obliged to give a detail of all these rules, which have not the least foundation in reason, and are proper only to be confuted.

The fore-mast is in length twice the breadth and one quarter more ; and its diameter, as well as that of the other lower masts, is about the 39th part of the whole length ; others make it nine tenths of the length of the main-mast.

The length of the bowsprit, is the breadth and half breadth of the ship, and its diameter the twenty-seventh part of its length ; so if a ship be 40 feet broad, the bowsprit will be 60 feet long, and $26\frac{1}{2}$ inches diameter at the bed, and at the cape it will be half what it is at the bed.

Lastly, the mizen-mast is, in length, the breadth and three quarters of the breadth of the ship ; and its diameter, at the partners, as many inches as seven sixteenth parts of the main breadth is feet, or rather, the forty-eighth part of its length.

Proportions for Top-masts.

The maintop-mast, in length, is the breadth and half breadth of the ship, which makes it equal to the bowsprit ; the diameter at the cape is about the forty-third part of its length.

The foretop-mast, in length, the breadth and three eights of the breadth ; the diameter, at the cape, the forty-third part of the length.

The mizen-top-mast is half the length of the main top-mast ; and its diameter, at the cape, half the diameter of the main-top-mast.

The main topgallant-mast is five twelfths of the length of the main-top-mast ; and it is half the diameter.

The fore top-gallant-mast is four sevenths of the length of the fore-top-mast.

The spritsail topmast is, in length, two fifths of the main breadth, and its diameter generally as many inches as there are feet in seven thirty-six parts of the breadth ; that is, somewhat less than the twenty-fifth part of the whole length.

Proportions for Yards.

The main-yard, in length, is twice and one sixth part of the main breadth ; the diameter, at the slings, one inch to every foot in two thirds of the main breadth ; or, which is the same thing, the thirty-ninth part of the whole length : The yards are of a quite different figure from the masts ; they taper from the slings towards the yard-arms ; the diameter, at the end, is one third of that at the slings.

The main-top-sail yard, in length, is the main breadth and quarter of the breadth ; the diameter, at the slings, half that of the main yard,

The

The main-top-gallant yard, in length, is three quarters of the main breadth ; and the diameter, at the slings, half of that of the main top-fail yard.

The fore yard, in length, is exactly twice the main breadth of the ship ; its diameter, at the slings, one inch to every foot in five eighths of the breadth.

The fore-top-fail yard is, in length, the breadth and sixth part ; and its diameter seven fifteenths of that of the fore yard.

The fore-top-gallant yard is, in length, two thirds of the breadth ; and its diameter half that of the fore-top-fail yard.

The sprit-fail yard, in length, is the breadth and one quarter ; and its diameter, at the slings, one inch for every foot in the third part of the breadth, which will be half the diameter of the main yard.

The sprit-fail top-fail yard, in length, is three quarters of the breadth ; and its diameter seven sixteenth parts of that of the sprit-fail yard.

The mizen yard is inclined, on account of the triangular form of the fail, and is the hypothenufe of a right angled triangle ; it is, in length, twice the breadth of the ship, and its diameter one inch to every foot, in one third of the breadth ; at the lower arm it is two thirds, and at the upper arm one third of the slings.

The mizen top-mast is, in length, three fourths of the breadth ; and its diameter, half that of the mizen yard.

Of the proper Figure of Masts and Yards.

Our readers, says our author, know very well that the masts, as well as the yards, are round, like cylinders, or cones ; but, perhaps, they imagine the sides are strait.

The best mast-makers make the sides of their masts curves, which form an arch of an ellipse. Our author here shews us how they form these curves ; for which we refer to *Chap. VII. Sect. I. pag. 106.* of the foregoing Treatise ; and proceed to the 6th chapter, where he makes some remarks and experiments on the before-mentioned proportions.

It is easy to judge, that the dimensions of the fails are regulated by that of the masts and yards.

The main-mast, of itself, is 120 feet ; the main-top-mast 72, and the main-top-gallant mast 30 feet , a monstrous height, when all these are on end ; and they are proportionally so in lesser ships : If the mariners would but attend to what they see every day before their eyes, they would easily be convinced, that it would be a great advantage to shorten them prodigiously ; and, if they please, make the yards longer, to gain what they

Supp.

D

lose

lose in the height of the masts. A small sail, when very high, will have more power to make a ship heel than to go a-head ; because, being placed at the end of a long lever, it is removed at a great distance from the center of gravity ; and whereas a larger sail, when placed low, has less power to heel the ship ; yet it does not hinder it from exerting all its effort in respect of sailing. All that the mariners have to plead for this rule is, that experience, and the universal consent of all nations, are on their side ; but we can assure them, experience, instead of favouring them, makes quite against them. There are daily instances of ships being dismasted at sea ; and when they have got up jury-masts, have sailed as fast as with the proper masts ; on the contrary, when they give a ship taunter-masts, she will not sail so fast as before ; an instance of this happened some years ago in his majesty's ship the *Content*, which they masted beyond the common rules ; or, perhaps, only observed them to the utmost rigour, and immediately she lost a great part of these advantages ; a certain mark that the masts are too high.

We perfectly agree, with our author, that when ships are dismasted in a very hard gale of wind, and the sea running very high, they will sail better with jury than with their proper masts, even when the top-gallant masts are struck, and all their sails handed ; but when the storm abates, and becomes moderate, so that a ship can carry top-gallant sails, it is presumed she would soon run another ship, with jury masts, out of sight.

But the height of the masts, says our author, is not the only fault that attends these rules ; there is another secret evil which they carry in their bosom ; they do not conform to the laws that should be observed in ships of different dimensions. If one ship is twice as long, and twice as broad, they make the sails of this last double the dimensions of the first ; but, as all ships are allowed to heel, a small ship should have a great deal less sail, in proportion, than a great ship : Supposing one ship half the dimensions of another, the small ship will only be the eighth part of the solidity, and the eighth part of the weight of the great one ; and, as it is the weight that opposes the wind, when it makes its effort to overset, or at least to heel the ship, she will have but the eighth part of the absolute force which is necessary to sustain the sail ; but this same force, which is diminished to one eighth part, is collected in the center of gravity, and applied with double disadvantage. Seeing all the dimensions are less by one half, the center of gravity will be but half the distance below the decks, or load-water line ; so the relative force, by which the weight of the ship opposes the effort of the wind, is only the sixteenth part of what the large ship has. In order to judge if these rules be good or bad, we have
only

only to examine if the relative force, which the wind has to overfet a small ship, be likewise diminished to a sixteenth part ; and, if they agree, the equilibrium will not be destroyed. This will be a mark that the rules are perfect, and we may continue to make the masts proportionate to the other dimenſions of ſhips.

But when the dimenſions of the ſails of ſmaller ſhips are half the dimenſions of the large, the ſurface of the ſails is only diminished one quarter : It is true, the center of that effort is but half the height above the ſhip, and, of conſequence, applied to the lever of only half the length : But, when all is conſidered, the relative force which tends to overfet, is only diminished to one eighth part ; whereas the other is diminished a ſixteenth part, as we have juſt now proved. It is plain then, that the force of the wind will predominate, being two-fold too great ; ſo that if the great ſhip be properly maſted, the ſmall one cannot be ſo likewise, but will be in danger of overſetting.

To ſpeak in more general terms, the relative force with which the ſhip oppoſes the effort of the wind, is diminished in proportion to the ſquare of the ſquare of the keel, or of the breadth and the weight ; or the abſolute force is diminished in proportion to the cubes. But the relative effort of the wind is not diminished, but as the cube of the keel, or as the cube of the breadth ; ſince the abſolute force of the wind, which is proportioned to the ſurface of the ſails, is diminished but as the ſquare ; and that the height of the maſt, which ſerves as a lever to that force, diminifhes only in proportion to the keel, or to the breadth ; ſo, in ſmall ſhips, the force which they have to ſuſtain the preſſure of the ſails is always diminished, in a greater proportion, than the relative force of the wind to overfet them ; and, of conſequence, if there be an equilibrium betwixt theſe two forces in large ſhips, it cannot ſubſiſt in ſmall, the firſt being too little, and the force of the wind too great. It follows then, that the common rules are defective, and will be at leaſt ſubject to one of theſe two inconveniencies ; for the ſmall ſhips, being over-maſted, will not be able to carry ſail with ſafety ; and, on the contrary, the great ſhips, for want of ſufficient maſts, will loſe the advantages the taunt maſts would procure.

The common rules being thus found defective, we cannot ſubſtitute others ſo ſimple in their room ; but, if we had but one ſhip properly maſted, we might, by that, regulate all the maſts of ſimilar, or nearly ſimilar ſhips. The relative force which ſhips have to ſuſtain the preſſure of the ſails, is as the ſquare of the ſquare of their ſimple dimenſions ; and the relative force, which the maſts have to overfet, is as the breadth

of the sails multiplied by the square of their height; since this height augments the extent of the sails, and at the same time makes the center of their effort higher: On the other hand, we can scarce dispense with regulating the breadth of the sails by that of the ship; we may make them more or less, but they should always depend on one another. So, since the relative force of the ship, to sustain the pressure of the sails, is as the square of the square of the breadth, the relative force which the sails have to make her heel is as the product of that same breadth, by the square of the height of the mast: But if there be an equilibrium betwixt these two forces, there will be an equality of ratios betwixt the two quantities that express them; and this equality will subsist if the two quantities divided by the breadth. Hence it follows, that, to have two similar ships properly masted, the squares of the heights of their masts must be as the cubes of their breadths, or of their lengths. This theorem may serve as a rule; and it will always be easy to determine the dimensions of the masts of any ship, provided we have another properly masted, which may serve as a standard.

It seems there can be no inconvenience in regulating all masts by those of the third class. In a ship of the third class, which is 137 feet long, the sails on the main-mast are generally about 118 feet high. In order then to find the height of the sails of a similar ship, which is 83 feet long, we have only to make this simple proportion: As the cube of 137 is to the square of 118, so is the cube of 83 to the square of the height of the sails, on the main-mast of the second ship; this square is 3096; and, of consequence, the required height of the mast is about 55½ feet; which, by the common rules, would be 71¼ feet. Tho' this operation is not long, it may be shortened by the logarithms.

But if the second ship is not similar to the first; if she be either broader or narrower, deeper or shallower, the masts must undergo a second change in proportion to the breadth; that is, if the ship, which is 83 feet long, instead of 23 feet broad, according to the common rules, be only 15½, or two thirds of 23, the height of the mast must be only 37½, instead of 55½. It is easy to remark, that the ship being the same length, but a considerable change in the breadth and depth, the height of the masts must receive a proportionable change.

For, supposing that the breadth of the sails is regulated by that of the ship, and that the height of the mast is likewise changed in proportion to the same breadth of the ship, the extent of the sails, and, in consequence, the absolute impulsion of the wind, will be in proportion to the square of that breadth, and its relative force in proportion to its cube; at the same
time

time that the relative force with which the weight of the ship resists the inclination, is proportioned to the same cube, and not to the square of the square, since the length of the ship is supposed still the same; for it follows from thence, that the alterations made in the sails, answer exactly to those made in the breadth of the ship, and that the equilibrium is no ways altered. If the breadth be doubled the sails will be doubled, both in breadth and depth; so the surface will be quadrupled; and, when the height of the center of gravity is likewise doubled, its force will be eight times greater; but if the relative force of the wind, to overset the ship, be eight times greater; on the other hand, the weight of the ship which opposes that has eight times greater force, and then we shall have nothing to fear. The ship in effect has the same number of vertical sections perpendicular to the keel, which are the elements of the solidity, but each will be quadrupled, and the quadrupled weight of the ship, being situated twice as low, or with double advantage, since the depth is likewise doubled, will have eight times the force precisely, as is necessary always to retain an equilibrium with the effort of the wind. We now perceive the propriety of joining this second rule with the former, which every one may easily do, who has one ship properly masted, by which to determine the dimensions of the masts of all other ships, even of those which are not similar, provided the vertical sections of the immersed part be similar.

The first rule is, that the squares of the heights should be as the cubes of the simple dimensions.

The second is, that the heights of the masts should be proportionate to the breadth of the ships, provided they be the same length.

These two rules being admitted, we may use the best we can pick out of the common rules, and examine the heights of the masts of each ship, as if similar to those of the third class, as they build them at this time; and then we need only enlarge, or diminish, the sails, and the heights of the masts, already found, according as the ship is great, or small.

We may find other rules, which tend to the same end with the preceding. As for example, a third is, that in ships of the same breadth, but of different lengths, the heights of the masts should be as the square roots of the lengths; for the relative force which these ships have to sustain the pressure of the sails, or to oppose the inclination, is proportionate to their lengths; seeing the other dimensions are no ways altered. The center of gravity is neither raised, or lowered; it is only the whole weight that is greater or less, according to the length; and the relative force will always

always be in the same proportion : But when the breadth of the ship continues the same, that of the sails will likewise be the same ; and the relative force they have to make the ship heel, depends wholly on their height, but that is two ways : The first is, because the height of the mast will increase the surface of the sail exposed to the wind ; the second is, because the center of effort is raised, or the lever is longer ; so the relative force of the sails increases the square of their heights, and in case of an equilibrium, that square must be proportionate to the length of the ship, which expresses the other relative force : And of consequence, the heights of the masts and sails should be proportionate to the square root of the length. Supposing that, without altering the breadth and depth, we should make the ship four or nine times longer ; we need only, according to that rule, double or triple the heights of the masts. Lastly, if we add this third to the second above mentioned ; namely, that in ships of the same length, but of different breadths, the heights of the masts should be proportionate to the breadth, we may from thence deduce the following fourth theorem.

In ships of different lengths and breadths, the heights of the masts should be in a compound proportion of the breadth and of the square root of the length, or they should be as the products of their breadths, by the square roots of their lengths.

Such of our readers, continues our author, as are not well versed in geometry, may easily be convinced of the truth of the most part of what has been said on this head, by trying experiments. If the heights of the masts should have the same proportion in all ships, it must hold in the smallest as well as in the largest ; and, on the contrary, if those rules are erroneous, the true way to discover the fault will be, to mast an enormous large ship by these rules, and likewise a very small one ; perhaps one or two feet long ; this will be, as the saying is, hitting the nail on the head. We may by this way bring the rule to such a proof, as may be deemed the true touch stone. When I was at *Havre de Grace*, continues our author, and ruminating on these things, I caused two small ships to be made perfectly equal ; and of the same form with the *Gazelle* frigate, building at that time for the king. My two small ships were each about 18 or 20 inches long, I cannot be positive to the exact length ; but this I may venture to assert, that they were exactly similar to the frigate, and one of them masted according to the established rules. I took upon me to mast the other, which I did not to the utmost perfection, that I might depart as little as possible from the common rules. In short, we gave the two ships the same loading and ballast, we carried them to a piece of water of sufficient

sufficient extent for our purpose, where they were exposed to the whole force of the wind, which then blew pretty hard; the experiment was scarce begun, when that mast fell in all respects similar to the *Gazele*, overset topsy-turvy a hundred times, to the great astonishment of all the spectators: Not considering that although all the parts could be made proportionate to those of the frigate, but 50 or 60 times less than the corresponding parts of the frigate, yet they could not at all abate the fury or force of the wind, and by this means they exposed the little ship to a perfect storm so furious, that the greatest ship could never encounter. It is granted, continues *M. Bouguer*, that the sails of the small ships are 60 times less than those of the frigate; and therefore the impulsion they receive, will be 3600 times less than those received by the frigate, allowing the wind to blow with the same force, and the effort of the wind to overset the ship, will be 216,000 times less. But the force which the weight of the small ship has to recover or right herself, is likewise 60 times less, for the weight itself is become 216,000 less, and when applied to a lever, 60 times shorter, it should have 1,296,000 less relative force. After this, it is no ways surprising, that the small ship which has 60 times less force, in proportion to the *Gazele*, to sustain the pressure of the sails, should not for one moment resist the effort of the wind, not even when great part of the sails are furled; and several other expedients tried by many who interest themselves too much to preserve these proportions, and save, if possible, the credit of the common rules. I fairly own that the model I made overset likewise several times; because, as I observed before, I satisfied myself in making the dimensions of the masts, nearer to the true, only in retrenching simply the principal defects in the common establishment; and the wind at the same time blew in heavy squalls, but the other small ship, after they had reefed part of their sails, overset 20 or 30 times to one of mine, which is a plain proof that the masts should not be proportionate to the other parts of the ship.

In the seventh chapter, he treats of the names and uses of the ropes, which constitutes the standing and running rigging; which concludes the second section.

In the third section, he treats of the absolute relative force of solids, whether wood, iron, or any other metal used in shipping, and endeavours from thence to make a general rule, for determining the scantlings at every particular piece of timber in a ship: He also considers, whether the common methods are sufficient for preventing a ship's hogging or cambring; this takes up four chapters; but as *M. Dubamel* has given us a
table

table of scantlings and dimensions, we refer our readers to the Appendix for determining that point.

In the fifth chapter, he gives us the following account of the solid of least resistance; that is, such as is not liable to be broke in one part more than in another.

Seeing it is certain, that in all bodies whose elementary slices form similar figures, the relative resistances are in proportion to the cubes of the diameters of their thickness, we may from that principle determine the figure of the solid of least resistance, that is such as is not liable to be broke in one place more than in another.

Suppose a power applied to the top A of the body A B, *Fig. 9*, and acts at the upper end in the direction A G, perpendicular to the axis of the solid, of which all the elementary slices are supposed to be either squares, or cylinders; this power will have more or less relative force to break the body according to its distance from that part which bears the greatest strain. If that part be near to the top, the relative force of the power acting on A will be weak, but stronger when at a greater distance; it will always be proportionate to that part of the axis A C, which serves as a lever to the power: Now the relative resistance of solids, which are as the cubes of their diameters, should be equal to the relative efforts of the power that preserves the equilibrium; so the cubes of the diameters at different parts of the lengths, should be in proportion to the lengths of the parts of the axis; consequently the solid of equal resistance in all its parts, should be a conoid formed by the first cubick parabola. A power at eight times the distance will have eight times the effort to break the solid, on which account the diameter at that place must be double that which is at the top, where the power is supposed to act. If the power is 27 times the distance, it will have 27 times more purchase; but if the diameter at that place be three times bigger, it will be able to sustain that whole weight.

We need not observe that this should be the figure of masts; it will be proper here to shew how this cubick parabola may be described, which may be done by the following method, delivered to us by our author.

Divide the length into 64 equal parts, and the diameter at the partners, into four equal parts. In order to determine the diameters at these several parts of the length; at 27 parts of the length, the diameter is three fourths of that at the partners; at 8 of the length of the diameter, half that at the partners, and at the first division of the length, the diameter one fourth of that at the heel.

Note,

Note. The parts of the length are accounted from the top, and in order to find the intermediate points betwixt these, see the following table.

Parts of the length.	Diam.	Parts of the length.	Diam.	Parts of the length.	Diam.	Parts of the length.	Diam.
60	3.91	45	3.56	30	3.11	15	2.47
55	3.8	40	3.42	25	2.92	10	2.15
50	3.68	35	3.27	20	2.71	5	1.71

In regard to the yards, they should not have the same figure, they should terminate in a point at each end, and each half should be formed by the revolution of a second cubick parabola. It is easy to perceive the reason of this difference; that power which tends to break the yards is not only applied at a less distance towards the extremities, but is also less, because the effort of the sails being distributed the whole length of the yard, there will be only that force which exerts itself on each part of the yard. The whole effort which the mast should sustain, is applied at the top, so it is always the same absolute force which tends to break the mast; whereas in the yards, the absolute force is greater towards the middle: The middle of the yard has not only the greatest effort to sustain, but this force is likewise applied at a greater distance. If we examine the effort of the sail at one quarter of the length of the yard, we shall find it but one half of that which it is at the middle, and, besides, the center of its effort is applied but at one half of the distance. In one word, the relative forces which tend to break the yards are, as the square of their distances from the next yard arm, and as the resistance should be in an equilibrium with these forces, it must follow that the cubes of the diameters be in proportion to the squares of the distances from the yard arm. Hence, if we divide half the length of the yard into 64 equal parts, and the diameter at the slings into 16, the diameter at 27 parts of the length accounted from the yard arm, must be nine sixteenths of that of the slings; at 8 parts of the length, the diameter must be one quarter of that at the slings, and at one sixty-fourth of the length, the diameter must be one sixteenth of that at the slings.

Our author, then considers the masts that should be made of several pieces, being too large for to be made of one tree, and thinks they should be of a different form; at the same time, he tells us, the mariners do not conform to any of these proportions; and that they are as much deceived, in respect of the figure, as in the length; though, they are very sensible, the figure of masts should differ from that of the yards. The builders, however, says he, have found to as great perfection as possible the proportion

Supp.

E

portion

portions the diameters should bear to the other dimensions ; for when they discovered the weakest part, they have made them bigger at that place, and, by the mere dint of repeated trials, have brought that point to as great perfection as could have been done, by the assistance of geometry.

In the sixth and seventh chapters, he considers the strength of the cordage, which concludes the first book.

In the second Book, he considers the ship when a float, and at rest.

In the first section, which he divides into six chapters, he treats of the weight of a ship, and the force of the water to sustain that weight.

The first three chapters are chiefly employed in prescribing rules to ascertain the precise draught of water a ship should draw, when properly loaded ; which he performs by measuring the immersed part, and thereby discovers if her load-water line corresponds to that in the draught ; the substance of which M. *Dubamel* has extracted, for which we refer to the Abridgment, Chapter VIII.

The other three chapters are wholly taken up in gauging of ships, and determining their tonnage, either in weight or bulk, and regulating the fees for anchorage, and other duties, which are regulated by the tonnage.

This concludes the first section ; and, in the second, he treats of the weight of the ship, and the proper position of the center of gravity, and gives rules for finding it. This with his remarks, takes up ten chapters, which M. *Dubamel* has given us in his second edition, the translation of which is hereto annexed, to which we refer ; but we must not pass over what M. *Bouguer*, says of the mechanick way of finding the center of gravity.

All the mechanicks, says he, know how to find the center of gravity of any body by suspending it. It is worthy to be remarked, continues our author, that this method may be very useful, and easily executed in the naval arsenals, where they have ready prepared every thing that is necessary for that purpose : All that is required is only to make a block of wood exactly similar to the immersed part of the ship, and proportioning all the parts of the block to the corresponding parts of the ship, by a scale of one fourth or one third of an inch, or any other convenient space, to one foot of the corresponding parts of the ship ; care must be taken to have the wood as light as possible. The block being thus prepared, may be suspended by a piece of packthread, in different situations ; if we conceive the packthread produced, it will point out the center of gravity. Notwithstanding the simplicity of this practice, our author says, it will be convenient

convenient on some occasions to use other methods, which may be more directly applied towards finding the center of gravity. — Thus far our author.

We shall here add, that some useful discoveries may be made by models, or blocks, and this, we conceive, with as great certainty as by calculation; for it must be allowed by the nicest calculators, that the *data* taken from the draught of a quarter scale, may be liable to great errors; but, upon strict examination, we may venture to assert, that there are very few ships that have both their sides exactly equal in every respect, and there need be no more convincing proof of this, than suspending the block by a piece of pack-thread fastened to a hook in any part of a strait line, drawn from the middle line of the stem to that of the post. This hook may be moved forward and aft to different places in the middle line, and a plummet suspended from the upper part of the midline of the stem, and another from the upper part of the middle line of the post, if the two sides be exactly of equal dimensions, and likewise homogeneous, they will be of equal weight: A plane passing through these three lines, whatever part of the middle line the hook be in will likewise pass through the middle line of the keel, stem, and post; a block that will stand this proof may be truly said to be a most valuable piece of workmanship, executed to the greatest possible perfection, and may be deemed the master-piece of the art, and must redound to the great honour of the workman.

The block being thus provided, and suspended by the hook, the plumb-lines at the stem and post at the same time corresponding to their middle-lines, and to that which suspends the block, we may hold a baton out of winding, a term well known to the shipwrights, with the line that suspends the block, and with a pencil draw a line on the block; a plane passing through this pencil line, at right angles to the keel, and passing likewise through the line that suspends the block, will likewise pass through the center of gravity, which, therefore, must be somewhere in this plane; again, move the hook to some other part in the middle line, and let the block be suspended from that point; draw also another pencil line out of winding, with this last line of suspension: The intersection of the two pencil lines will give the height of the center of gravity above the keel, and likewise its distance from the post and stem; and if the hook be moved to any other parts in the midline, and a pencil line drawn as before, it will likewise intersect in the same point, or let there be never so many points assumed in the middle line, and the block suspended by each, and pencil lines drawn, they will all intersect in the same point, and as the center of gravity will always be in that plane which passes

through the middle line of the keel, stem, and post, it may, with certainty, be marked on the draught.

It must be allowed this will require the utmost nicety, and, if well executed, will agree exactly with that found by calculation, provided the dimensions be taken with an exceeding good scale of equal parts, for which we judge the diagonal scale of equal parts in Plate II. of the foregoing Treatise to be sufficient.

Having thus found the center of gravity of the immersed part, we may, by the like process, find the center of gravity of the whole ship, compleatly rigged, masted, and with all her guns, ammunition, provisions, &c. on board. In order to which the model must be compleated, her upper works, &c. similar to the ship, masted, rigged, and have the same number of guns, shot, casks, cast ballast, in short, every particular species that compose the whole weight of the ship, all similar to the respective species in the ship, that is, in proportion to the cubes of their similar dimensions. All these things being stowed in the model, they may be shifted fore and aft, higher and lower, till such time as by repeated trials the center of gravity of the whole ship may be properly situated with respect of that of the immersed part.

It must be allowed this will require the utmost care in the execution, but it must likewise be allowed, it will require no less care and accuracy to find the exact dimensions of the several sections of the ship, especially as every dimension in the ship is 48 times bigger than their similar ones in the draught, so that an error of a quarter of an inch in the draught, which is only the 48th part of a real inch in the ship, will occasion an error of 110592 cubick quarters of an inch in the ship, provided the error be in all the three dimensions, *viz.* length, breadth, and thickness.

There are several models compleatly masted, rigged, with guns, anchors, &c. proportioned to those of the ship; such as have these in possession may make several useful experiments in water; a few of which we shall mention.

First, to find the whole weight of a ship when properly loaded to the proposed water-line.

To attain this, let the loadwater line be drawn with a pencil on the model, and loaded till that line come exactly to the water's edge, after which take the model out of the water, and let it be suspended till all the water drains off, and then weighed. The following proportion will give the weight of the ship; 1 is to the weight of the block, as the cube of 48 is to the weight of the ship. *Note,* this may be done without the masts, and the block may be loaded with sand, or any other ponde-

ponderous body, that will sink the model to any proposed draught of water. If the weight of the ship be given, we may find what the weight of the block should be by the reverse of this proportion. We shall illustrate this by an example.

Example. Admit a model, when properly loaded, weighs 163 ounces, what will be the weight of the ship in tons?

As 1	0.
Is to 48 ¹	5.043723
So is 163	<u>2.212188</u>
	7.255911
Subtract	<u>4.554368</u>
Tons 503	2.701543

As the index of this logarithm is 7, the natural number must consist of eight places, and the answer will be in ounces, which cannot be had in the common tables. We shall therefore reduce them to tons by the common rules of reduction. First divide the ounces by 16, gives pounds; divide the pounds by 112, gives hundreds; lastly, divide the hundreds by 20, and we have the answer in tons. Now all this may be done by subtracting the sum of the logarithms of these three divisors from the sum of the logarithms of the first and second term, as in the preceding operation.

16	1.204120
112	2.049218
20	<u>1.301030</u>
Sum	4.554368

Hence we have the following general rule : To the logarithm of the weight in ounces, add the constant logarithm of 48¹, which is 5.043723, and from the sum subtract the constant logarithm 4.554368; the remainder will be the logarithm of the number of tons. It must be observed, that if the scale be not a quarter of an inch to a foot, we must not take the logarithm of 48¹, we must find how many of the parts that represents one foot in the draught will make a real foot; as for instance, if the draught be a three eighth scale, it will take 32 of them to one foot, so that in that case we must take the logarithm of 32¹; if by a half inch scale, the logarithm of 24¹; if by a three quarters, the logarithm of 16¹, &c.

Secondly, we may, by the same rule, find the weight of the ship when launched : It is only loading the block to the same draught of water with the ship when launched, and then taking the weight in ounces, and

and use the same process as before; we may repeat the same when ballasted, when rigged, in short, we may find the weight of the masts, guns, provisions, &c. or how much weight will be necessary to be put on board to make her draw an inch more water. It must be understood that this rule will give the tons, in the common acceptation of that word; for by that is meant the builders tons; for finding which there is an established rule, which may vary according to the custom of the place she is built in. The freight of goods in the merchant service is either in weight, or bulk; the weight is 20 cwt. to one ton, and 40 cubick feet make one ton.

The general rule for determining the tonnage of ships taken into his Majesty's service.

1. Let fall a perpendicular from the back of the main post at the height of the wing transom, to the rabbet of the keel produced.
2. Set forward for that two inches and a half for every foot in height for the rake of the post, and from that point measure to the perpendicular let fall from the fore-side of the stem, observing, if the ship is not on an even keel, to make use of a square applied to the base board.
3. Deduct three fifths of the extreme breadth out of that length, the remainder is accounted the length of the keel for tonnage.
4. Multiply this length by the extreme breadth, and this product by the half breadth; divide this product by 94, the quotient will give the required tons; or, which is the same thing, multiply the length of the keel by the square of the breadth, and divide the product by 188; the quotient will give the tons.

Example. Keel for tonnage 144.5 feet; breadth extreme 51; required the tons? The following is the operation performed by logarithms:

51 ^a	3.415140
144.5	2.159868
	<u>5.575008</u>
188	2.274158
	<u>3.300850</u>
1999 tons	

(See this operation performed by the sliding rule, p. 99 of the foregoing Treatise.)

In the merchant service take the depth of the keel below the rabbet, and set that off from the rabbet of the post, then proceed as before; for boats, in general, proceed from the back of the post, and proceed as above.

It is the general practice of the builders to measure the tonnage by the real dimensions of the ship, when upon the blocks. The builders and mariners agree in this point, and experience proves beyond dispute, that few,

few, if any ships, are exactly similar to the draughts; and, indeed, it is impossible they should, unless the thickness of the plank be laid down in the draught, which, perhaps, may be one of the most intricate operations in the practical part of ship-building; however, I shall attempt it in another place. The chief design of laying down the proposed dimensions on paper, and then in the loft, is to determine the exact form and bevelling of every timber in the ship, which is now done to so great perfection in his Majesty's dock-yards, that they want very little reconciling when going to be planked. As there is scarcely a possibility of ascertaining the true dimensions from a draught, it seems there can be no great dependance on the calculations mentioned by our author. He has, to his great honour, carried his investigations to the utmost nicety; having considered the minutest circumstances, and the alterations the ship undergoes in all different situations, and has brought the theory of ship-building to as great perfection as the nature of the subject will permit, though very few shipwrights can follow him in his deep researches.

Our author, in the eleventh chapter, shows how to find, by a simple experiment if the center of gravity of a ship be properly situated, even after she is built.

It would, says he, undoubtedly be of great advantage, after a ship is built, rigged, and loaded, to have it in our power to be well assured, even when she is in the harbour, that the center of gravity be properly situated with respect to the metacenter.

Sometimes there are many things ranged and placed in a very different manner. The consumption of ammunition and provisions in a long voyage is very considerable, and it will be necessary to know what changes result from thence; and this is what may be had by a very simple experiment. We are obliged for the first idea of this to Father *Hofte*.

If we place a weight P , on the outside of the ship OEC , *Fig. 10*, at the outer end Q of a sparr, laid across the ship, this will make the ship incline to a certain point, at which time there will be an exact equilibrium betwixt the weight suspended without the ship, and the whole weight of the ship, on each side of the line YZ , in the direction of the vertical effort of the water. The common center of gravity G , is in the same vertical with the metacenter, when the ship is in an horizontal situation; by the metacenter our author understands that point, above which the center of gravity should never be placed. The more the ship inclines, the further will the center of gravity G be removed from the line YZ , the vertical of the metacenter, and it is plain that GT , the distance from that line, is always in proportion to the sine of the

the inclination ; at least, when the inclination is but small. Now if that distance, and likewise the whole weight of the ship be known, we have likewise its moment, or the relative force with which that weight acts, in endeavouring to right the ship, and bring her again into an horizontal situation ; but since both the situation, and likewise the weight that produces the inclination are known, we may from thence know if the moment of one be equal to that of the other, and thereby easily discover if the center of gravity be in that very point we propose.

We cannot be too nice in taking the quantity of the angle of inclination, for the success of the whole experiment depends on this : To attain this, we may use a level line for the sensible horizon of the sea, or a plumb-line fastened to the head of the mast, and take its distance from the foot of the mast, both when the ship is upright, and likewise when she heels ; the plumb-line seems to be the most convenient, because we have thereby immediately the proportion in which the center of gravity recedes from the vertical of the metacenter, which will always be in proportion to the distance of the plumb-line from the foot of the mast. We must be very careful, during the whole time of the operation, to render all the circumstances absolutely the same, that we may be well assured the inclination is produced only by the weight applied to the outside of the ship : No doubt, this will require the assistance of many hands, to put every thing requisite in its proper place, but they must all withdraw, when the distance of the plumb-line and the other dimensions are measuring. The weight of two or three, or sometimes even ten men, need not be regarded ; whereas the weight of the whole crew would produce a very sensible alteration ; and, I conceive, the crew might be disposed to great advantage in this experiment, as they may be easily moved from one place to another.

We may, by this means, find the center of gravity of the ship, provided we know only the metacenter ; for, having the quantity of the weight that produces the inclination, and examining RZ , its distance from the metacenter, or from the vertical that passes through that point, and on which the effort of the water exerts itself, we have likewise its moment, or its relative force, which is equal to that of the weight of the whole ship, since these two exactly ballance one another ; so it is only dividing this moment by the whole weight of the ship, and the quotient will give us the distance of the center of gravity, G , from YZ , the vertical of the metacenter. If the weight that makes the ship incline be 5 tons, and its distance from YZ be 30 feet, its moment will be expressed by 150 ; and if this moment is divided by 1800, which is supposed to be

be the whole weight of the ship, we shall find that the distance of the center of gravity is from the vertical, YZ , one inch. After this, it will be easy to discover how far the center of gravity is below the metacenter g ; since there will always be the same proportion betwixt the distance of the plumb-line from the foot of the mast, and the height of the mast, that there is betwixt GT , one inch, the distance of the center of gravity, G , from YZ , the vertical of the metacenter, and gG , the distance betwixt the metacenter and the center of gravity. If a plumb-line, of 50 feet long, is one inch distant from the foot of the mast, we have this proportion, $1 : 50 :: 1$ (inch, the distance of the center of gravity from the metacenter) : 50 inches, which makes Gg , the distance of the center of gravity, below the metacenter 4 feet 2 inches.

We may remark, that, in order to determine this exactly, it is not necessary to know the precise point in which the metacenter lies; it may be supposed in the middle of the breadth-line OC on the upper deck.

The smaller the weight is that makes the ship heel, so much the greater must be its distance from the ship; however, an error of some inches, in the horizontal distance of the weight, will be scarce perceptible.

In fine, where neither the situation of the center of gravity, nor of the metacenter, is known, this experiment will at least have one considerable advantage, that thereby we may know if these two points are always situated in the same proportion with respect to one another. We may, by this means, be in condition to reap the profit of all experiments made in former voyages, and easily find the ship's best sailing trim, which the mariners call her seat in the water; and it is only by these repeated trials, that hitherto they have found it out. Though the builders always draw a water-line on their draught, to determine the precise draught of water the ship will draw when loaded; it is but too true, that they have no certain method to ascertain this, and are altogether ignorant what should be the difference of the draught of water afore and abaft.

All ships have a scale of feet and inches on their post and stem, to determine the draught of water afore and abaft: We may, by this scale, discover if the whole weight, and if the goods be stowed exactly in the same manner, with respect to the length of the ship, and likewise if the center of gravity be properly situated in respect of fore and aft. But tho' these be important discoveries, yet these alone are not sufficient; for, admitting we have all these, the center of gravity may be either too high or too low; to ascertain which, we must have recourse to the preceding experiment. Those who have the charge of navigating the ship,

Supp.

E

and

and flowing the goods, make particular mention in their journals, of the weight of the cargo, the number of guns, the exact draught of water fore and aft ; they need only make one remark more, which is, to specify the exact weight that will be necessary to be laid on the outside, in order to make her heel to a certain determined point.

When all this is given, it seems we know all the circumstances of the weight, which contributes to the safety and perfection of navigation ; for what more can be desired, but the exact quantity of that weight, and the precise point in which it is united. It does not appear that the mathematicians who have examined this subject, have proceeded on any other supposition, than to render our examination compleat : These researches must be carried further. The weight of the ship may be exactly the same, and the center of gravity may likewise be situated in the same point, with respect to its height, and yet produce different effects. The effect will be exactly the same while the ship continues in the same situation ; but it will be quite different, when the ship begins to rowl, and this may happen even in a calm, when a ship has no head way. If any exterior cause, as the continual motion of the sea, or a sudden shock of the waves puts the ship out of her horizontal situation, on recovering herself she contracts a motion which makes her incline to the opposite side, and her oscillations continue sometimes a considerable while ; because the exterior cause is renewed, and acts a second time, which perpetuates the motion : This concludes the second section.

The third section contains three chapters.

The first on the point, round which the ship rowls, and how far the weight will conduce to her rowling.

The second. The figure of the ship being given, and the distribution of its parts, to know the direction of the oscillations.

The third chapter is to find the changes produced on the rowling, by the transposition of some parts in the ship, with some remarks on pitching.

As M. *Dubamel's* remarks contain the substance of what our author has said on this subject, we refer our readers to our translation of his tenth chapter of his second edition, which is hereto annexed, and pass on to the conclusion of M. *Bouguer's* second Book.

After expatiating on the great advantages that will accrue to navigating, by a proper situation of the center of gravity. He says, no labour should be thought too great to obtain it ; and that the builders, endeavouring to make two ships equal in point of sailing, have made their bodies so exactly equal, and of the same figure, that no difference could be perceived

perceived in the very minutest article : But these ships were scarce out of harbour, when their difference, in point of sailing, shewed itself in a very great degree, to the extreme amazement of all the beholders. This great difference cannot be attributed to the chimerical causes, for they deserve no better name, to which they have recourse. Whence comes this difference, if not from the center of gravity, the situation of which they had given themselves no trouble to examine, if in the same place in both ? But granting that it may so ; yet when the cargo is differently stowed, and she inclines more, or rows to a greater or less degree ; the immersed part ceases to be the same, and of consequence the ship will, in this respect be different, and produce different effects. It may here be asked, if the two ships were to undergo M. Bouguer's experiment, and the center of gravity, metacenter, &c. are found exactly the same in both ; and, if then, there should be any considerable difference in point of sailing, whence this could arise ? For they are supposed to be rigged exactly both alike.

The chimerical causes, he mentions, are, that some imagine that a ship's sailing depends on driving wedges, in some particular places ; on setting up the rigging, which may be too tight or too slack, on a piece of sail being spread to the wind, or on a weight of 15 or 20 pound being suspended in a certain place, &c. he says there are not wanting seamen, who not knowing the causes of such changes, have ascribed them to some such causes, and assured us they have confirmed them by experience : And what is still more ridiculous, it is usual, on pressing occasions, to saw the gunwales, and to loosen some parts, whereby they imagine the ship's motion will be quicker, because they are more sensible of her motion themselves. This is, says our author, as if a post chaise badly slung would go faster, because they who are in it feel themselves more suddenly toft and tumbled about. What ever may be in these remarks of our author, we may venture to assert, that a ship, after being loosened, has got away from another that has gained on her very fast before.

M. Bouguer, in his third Book, examines the laws which fluids observe in their shock ; as the wind in striking the sails, and the water in encountering the fore part of the ship : He divides it into five sections.

The first section has eight chapters.

In the first, he considers how the impulsion of the wind on the sails, and the shock of water on the bow, contribute to the sailing, which he treats in a most elegant manner, as a specimen of which we shall give the following extracts.

When a ship sails out of the harbour, she acquires her motion by infinitely slow degrees; much after the same manner as heavy bodies, in their fall, arrive not at a certain velocity, but by an infinite repetition of the action of their weight.

The first impulsions of the wind greatly affect the velocity, because the resistance of the water might destroy them, for the velocity being at first small, the resistance of the water, which depends thereon, will be very weak; but the faster the ship goes, the less will be the force of the wind on the sails, whereas it is quite otherwise, with respect to the impulsion of the water, on the bow; because it augments in proportion to the velocity with which the ship sails. So the new degrees, which the effort of the sails adds to the motion of the ship are continually decreasing; whilst, on the contrary, those which diminish the resistance of the bow are continually increasing. The velocity is accelerated in proportion as the quantity added is greater than that subtracted; but when these two powers become equal, when the impulsion of the wind on the sails, has lost so much of its force, as not to act but in proportion to the force with which the resistance of the water acts on the bow, in the opposite sense; the ship then will go no faster, and will sail with a constant uniform motion. The great weight of the ship may be the cause of the ship's being so long in coming to her greatest velocity; but this weight makes nothing to the degree of velocity; and when the ship has once come to it, she afterwards goes on by her own intrinsic motion, and she can neither gain nor lose any new degree of velocity: She moves as by her own proper force *in vacuo*, without being afterwards subject, either to the effort of the wind on the sails, or the resistance of the water on the bow. If at any time the impulsion of the water on the bow should destroy any part of the velocity the impulsion of the wind on the sails will repair it, so the motion will continue the same; but it must be observed this will only be when these two powers act in a quite contrary direction to one another; otherwise, they will not mutually destroy one another. The whole theory of working ships, depends on this opposition and perfect equality, which should subsist betwixt the impulsion of the water, and the impulsion of the wind.

In the second chapter, he treats of the measure of the absolute shock of the water, and of the wind.

When, says our author, the water, or any other fluid, strikes a plane, every particle will act with greater or less force, according as the direction is nearer or farther from being perpendicular.

The

The effort of one particle is expressed by the sine of the angle of incidence ; but at the same time that each particle makes a greater or smaller impression, the number of these particles will be greater or smaller, according to their right, or oblique direction ; and this number is likewise expressed by the sine of the angle of incidence, so the impulsion is in proportion to the square of the sine of the angle of incidence. When the angle is right, the impulsion will be the greatest that it possibly can be ; whereas, when it is only 30 degrees, every particle will make only half the impression, and there will be only half the number that will contribute to the shock, so the effort will be only one quarter.

But it is not only the obliquity of the direction in which the fluid gives the shock, that makes the difference ; it is likewise more or less, in proportion to the absolute velocity, which it has, independent of the obliquity : As soon as the fluid moves faster, the shock becomes greater, and is in proportion to the square of the velocity. If the water, which for example, strikes a surface, acquires three times the velocity, every single particle will act with three times the force ; but as there will be three times the number that make their effort, the whole shock will be nine times greater. This is a property which is common to all fluids, which makes their efforts sometimes very prodigious. Salt-water, for example, running at the rate of one foot in a second, will have but a small effect, but if the velocity is ten times greater, the shock will be a hundred times greater ; a force sufficient to break thro' the thickest dykes.

Hence, when the same fluid strikes the same surfaces with different velocities and different obliquities, the impulsions are as the product of the squares of their velocities by the squares of the sines of the angles of incidence.

If not only the velocities, and the sines of the angles of incidence be different, but likewise the surfaces ; the impulsion will then be in proportion to the extent of the surface, which will, nearly, be as the product of the squares of the velocities, and of the squares of the sines of the angles of incidence, multiplied by the area of the plane, which receives the shock : I say, nearly, for it may happen that the shocks are not proportionate to the areas of the surfaces that receive them ; for instance, a surface of double the area may not receive exactly double the shock, on account of the greater or less difficulty with which the particles retire after having accomplished their shock.

Be that as it will ; if the preceding rules be admitted, we need only make some experiments on the shock of the fluids, by which we may judge of the force of the shock in all other cases. It may be admitted as a prin-

a principle established by experiments, that the perpendicular shock of salt water, whose velocity is one foot in a second, upon a surface of a foot square, will be nearly equal to one pound seven ounces. If the velocity be greater, the impulsion increases in the duplicate proportion : If the surfaces be greater, the effort is in proportion to their areas, and, lastly, if the shock be oblique, the impulsion changes according to the square of the sine of the angle of incidence.

Upon the whole, if the velocity of water, or of any other fluid, be known, we need make no doubt about determining the force of the shock ; but it is not so with respect to the wind. The densities of the air are very variable, and are seldom sufficiently known ; so it will be better to endeavour to determine the force of the wind immediately, without perplexing ourselves to deduce it from the velocities. There have been several instruments contrived by the ingenious for this purpose ; to those who are not furnished with any, I recommend the following, which is very simple, and I found it very useful in practice.

This Anemometer, is only a piece of light paste-board applied to a sort of steel yards, which performs its office by a spring. The paste board A B D E, *Fig. 11*, is 6 inches square, fastened to the rod C F, which is put into the pipe F G, and rests on a sort of spring in the bottom of the pipe ; the piece of paste-board being placed directly against the shock of the wind, the rod C F will press the spring with greater or less force, in proportion to the impulsion of the wind. There is a rowler at F, in the mouth of the pipe, on which the rod C F moves, to take off the friction. The rod being graduated, we have the quantity of the impulsion of the wind, in pounds and ounces, in the same manner that the steel-yard gives the weight of any thing else ; but as the wind may be variable, the impulsion may move the rod backwards and forwards ; so, to estimate the quantity of the impulsion, we must take a mean, betwixt the least and greatest. One of the principle advantages of this instrument is, that we need only place the paste-board parallel to the surface of the sails, without regarding the obliquity of the shock, by this means it will be easier to determine the quantity of the whole impulsion that makes the ship sail, and, from that, be able to judge whether the masts will be in danger. I presume it will not be safe to charge a foot square, with a weight of six pounds. In *France*, the velocity of the wind is about 50 feet in a second, if it be in winter ; but if in summer it will be about 60 or 63, and still more, over all the torrid zone. This is only its relative velocity, which it has with respect to the ship, whereas, its absolute velocity is much greater, and is sufficient to overset the ship, and if on land would

would overturn houses, and tear trees by the root out of the ground. The reason of what our author advances here, I take to be, that the houses or trees do not go from the wind; whereas, the mast of the ship, before it breaks, forces the ship a head, and as it were, runs away from the stroke, which cannot be the case of any thing that is fastened in the ground.

The Anemometer may likewise serve to measure the effort of the water, as well as that of the wind. In the builder's yards, where they have every thing that is needful for the purpose, they may easily make a small bow of wood, similar to the bow of the ship, and then, instead of the paste-board *ABDE*, *Fig. 11*, fix this small bow to the rod *CF*, which being exposed to the shock of the water, we shall then have the quantity of the effort in pounds and ounces; we may see, by the direction of the rod, in what direction the bow receives the shock. Lastly, we may repeat the experiment, by exposing to the shock of the fluid, a plane equal to the base of a conoid, which represents the small bow; by which we shall perceive how much the shock of the fluid is less on the bow, than on the midship frame. These mechanick experiments may help us to judge of the impulsions which surfaces receive in most cases; but the general method is, to reduce the impulsions which curve surfaces receive, to those which fall on plane surfaces, in order to which the curves must be divided into such a number of small parts, that they may be deemed strait.

In the third chapter, the impulsion of fluids, on different figures, is considered; at first on a bow formed by two strait lines.

Let the bow *BAD*, *Fig. 12*, be formed by the two strait lines *AB*, and *AD*, and the direction of the shock be in an infinite number of lines parallel to the axis *AC*. The angle of incidence will be equal to the angle *BAC*, or to half the angle *BAD*, and, if we multiply each side *AB* and *AD*, by the square of the sine of the angle of incidence, we shall have the whole absolute impulsion which exerts itself on each side, in the perpendicular direction of the line *EF*; let this be represented by the space *EF*, and form the parallelogram *EGFH*. The sides *EG* and *FH*, are parallel to the axis *AC*, and the other two sides perpendicular to it. It is plain, that *EG* and *FH* represent that part of the impulsion which exerts itself in a direction parallel to the axis; and it is as plain that it will be less than the absolute impulsion, in proportion as *BC* is less than *AB*. Since the triangles *ABC* and *FEH*, are similar $BC : AB :: EG : EF$; so, instead of working for the absolute impulsion on the sides *AB* and *AD*, which partly destroy one another, we need

need only work for the direct relative impulsions, which act in the direction of the axis, and mutually assist one another; but we must not multiply the square of the sine of the angle of incidence by the length of each side, AB and AD , for this would give us the absolute impulsion; we must multiply the square only by CB , or CD . By this means, we have the two direct relative impulsions; and then, if we multiply the square of the sine of the angle of incidence, by the whole base BD , we shall have the relative direct impulsion on the whole bow.

If the angle at A , formed by the two sides, be 60 degrees, the angle of incidence will be 30; and its sine, being half the sine of 90, the square of this sine will be four times less; whence the direct impulsion which the bow receives, will be but one quarter of that received by the base BD , since the angle of incidence is 45 degrees, and the square of it is half the square of the sine of 90 degrees.

He then considers the impulsion of the water on a bow, formed by a semicircle, and likewise on a parabolick bow, which concludes the chapter.

In the fourth chapter, he gives a general method of finding the impulsion on curve lines, which he introduces with the following preface.

The impulsion of fluids on several other curve lines may be had by an analysis purely geometrical; but it will be necessary to have recourse to algebra in these researches, as it is only by this means we can extend our views; for what is proved this way will be universal. We conceive then, that, instead of dwelling any longer on an examination which can only be applied to particular cases, we should aspire to make our discoveries general, which may be applied to all sorts of curve lines that can receive the shock of fluids.

Of the Impulsion of Fluids in respect of the Axis.

Let BAD , *Fig. 13*, be a curve line; AC its axis, AB and AD the two branches perfectly equal; let x be the variable parts, AC or AH of the axis, and let y be the corresponding ordinates BC and EH ; let dx express the infinitely small parts Hb of the axis, and dy express EF , the difference of the ordinates. Again, that I may not have occasion to return here a second time, I suppose the fluid to move in the oblique direction of the lines LeI , LeI , which make the angles FeI with the axis of the curve, or with the line eF , which is parallel to the axis. Let n represent the sine of 90 degrees, m the tangent of the angle FeI ; then $\sqrt{n^2 + m^2}$ will be the secant of the same angle.

The

The angle $F e I$ is the oblique angle the ship's true course makes with the keel, or the lee-way; now, supposing the curve $B A D$ be the projection of the bow upon an horizontal plane, and A its extremity, the angle of incidence will be $E e I$, and will be greater on that side of the curve where the fluid strikes it more directly, than on the other side, where it is more oblique. From the point I , let fall the perpendicular $I K$, on the small part $E e$, so shall $I K$ be the sine of the angle of incidence to the radius $e I$.

In order to find $I K$, the sine of the angle of incidence, our author has a very intricate algebraick investigation, by fluxions, and as it may be presumed, many of our readers are not so well versed in algebra as to follow him in these deep researches; I shall endeavour to explain the whole by right angled triangles.

All that he proposes by this long process, is, to find $I K$, the sine of the angle incidence $E e I$.

The angle $F e I$, the lee-way, is given, which suppose $11^{\circ} 15'$; then the angle $F I e$, its complement, will be $78^{\circ} 45'$.

Let $E F$ be 40 equal parts, and $F e$ 50 equal parts; then $E F : F e :: R : \tan. \text{angle } I E K = F E K$, now subtracting the angle $I E K$ from 90 degrees, we have the angle $E I K$, and this last angle subtracted from the angle $F I e$, there remains the angle $K I e$. The angles being thus found, our next business is to find the sides $E e$, $K I$, and $e I$.

In the right angled triangle $I F e$, $R : \sec \angle F e I :: F e : e I$; again, in the right angled triangle $I K e$, $R : \sin \angle I e K :: e I : I K$, the sine of the angle of incidence. Lastly, to find $E e$, the small portion of the bow which receives the shock; in the triangle $F E e$, $R : \sec \angle F E e :: F e : E e$. See this operation by the logarithms.

$E F$ 40	1.602060	Angle $F I e$ $78^{\circ} 45'$	
$F e$ 50	1.698970	Angle $E I K$ $38 \quad 40$	
R		Angle $K I e$ $40 \quad 05$	
Tan. $51^{\circ} 20'$	10.096890	Angle $K e I$ $49 \quad 55$	
Com. 38 40			
R		R	
Sec. $\angle F e I$ $11^{\circ} 15'$	10.008426	Sine $\angle I e K$ $49^{\circ} 55'$	9.883723
$F e$ 50	1.698970	$I e$	1.707396
$I e$	1.707396	$I K$	1.591119
R			
Sec. $\angle F E e$ $51^{\circ} 20'$	10.204267		
$E F$ 40	1.602060		
$E e$	1.806327		
Supp.			

G

Having

Having thus found IK , the sine of the angle of incidence, and Ee the part which receives the shock, multiply this last, by the square of the angle of incidence, and the product will be the absolute impulsion, as by the logarithms,

$$\begin{array}{r} IK \quad 1.591119 \\ \quad \quad 2 \\ \hline \quad 3.182238 \\ Ee \quad 1.806327 \\ \hline \quad 4.988565 \end{array}$$

The angle of incidence, on the other side, will be $27^{\circ} 25'$, the sine of which we may find by the same proportions.

I shall only remark on the whole, that our author supposes the angle of the lee-way to be known, on which the result of the whole process depends; and as there is yet no expedient found to ascertain that angle, even to a quarter point of the compass, it is to be feared we shall gain very little by this general rule, therefore it is needless to detain our readers on this subject, as the conclusions drawn from them are no ways to be depended on. Our author indeed attempts to determine the lee-way, which we shall consider in its proper place.

The inference he gives, from the preceding process, is the resolution of this surprising paradox, as he calls it, which is, that the relative direct impulsion depends neither on the nature of the curve which receives it, nor on the length of the axis AC , but only on its extreme breadth BD .

Let the curve BAD be an arch of a circle, parabola, or hyperbola; let it be a geometrick or mechanical curve, &c. so the breadth continues still the same; the impulsion it receives, in respect of its axis, by a fluid which strikes it at an angle of 45 degrees, will always be the same, and equal to half the square of the sine of 90 degrees, multiplied by DB the breadth; in other words, it will be half of that which DB would receive, supposing the fluid should strike it perpendicularly; since that strait line may be considered as the curve BAD , supposing the axis to be infinitely small.

Admitting all this, our author does not tell us how to apply this to the formation of the ship's body, nor yet how his angle of 45 degrees is to be found.

In his fifth chapter, he considers the impulsion of fluids on curve surfaces, particularly on a conick bow, and on a conoidale bow, formed by the revolution of an arch of a circle, which he investigates algebraically, and

and from thence infers, that a bow, formed by half the revolution of a quarter of a circle, meets with double the resistance in an horizontal that it does in the vertical, and concludes, that by consulting the trigonometrical tables, we shall find the whole or absolute resistance, which is composed of these two relative impulsions, exerts itself in a direction, which makes an angle of about $26^{\circ} 34'$ with the horizon.

In his sixth chapter, he gives a method to find the impulsion on curve surfaces, by dividing them into a number of equal parts, which may be deemed plain surfaces, for which we refer to our Appendix, translated from M. *Dubamel's* extracts.

In his seventh chapter, he has some remarks on the change of the impulsions on curve surfaces, when the fluid alters its direction, and observes, that without perplexing ourselves with examining all the oblique courses a ship may sail, it will be enough to calculate the resistance, when she sails in the direction of the keel. It is certain, says he, that the angle the ship's course makes with the keel amounts to an angle of 45 degrees or $54^{\circ} 44'$, to loose the advantage of the figure, and still less, to change it to a disadvantage. I have, continues our author, in a memorial, communicated to the Academy of Sciences in 1733, proved this truth *a posteriori*. When a plain surface, exactly circular, is exposed to the perpendicular shock of a fluid, the nature of such a conoid that should cover it in such a manner, as thereby to meet with the least possible resistance, has been discovered long ago; but this is limited to perfect conoids alone, and besides there is room to believe that it will not be the same in a direct and oblique course. In order to clear this point, which has embarrassed the greatest mathematicians, I not only assumed any figure for the base, but even supposed the fluid to strike it obliquely, and was well recompensed for my labour, for I thereby discovered, that tho' the conoids of least resistance be different for different bases, yet it will be the same thing in respect to the impulsion, whether the course be direct, or oblique to the keel. Hence, says he, we may be excused from calculating the resistance in oblique courses, for it may be attained by calculating the resistance in a direct course. We presume, our author means, whatever be the form of that bow that will meet with least resistance in a direct course, will likewise be the form of that which will meet with least resistance in oblique courses.

In the eight chapter, he pursues the same subject, and considers the lateral impulsion, which he concludes with the following remark.

The bow that meets with least resistance in a direct course, not only meets with least resistance in oblique courses, but is that likewise which is least

subject to drive to the leeward, which is a double advantage gained by forming the bow so as to give it that figure which will meet with least resistance in moving thro' any medium.

We have now given our readers a specimen of our author's method of examining the laws which the fluids observe in their shock; the wind in striking the sails; and the water in striking the fore part of the ship; which he comprises in the first section of his third Book. He proceeds, in the second section, by the same method, to attempt a general solution to all the problems relating to working a ship.

In the first chapter, he considers the velocity of the ship's sailing, in proportion to the velocity of the wind.

It has been always supposed, continues our author, that the velocity of the ship has no proportion to that of the wind. *M. d'Ons-en-Bray* was the first who thought this subject worthy of our attention, and it seems, has designed to reserve the resolution of this question to himself; the principles he was to proceed upon, can only be executed by experiments taken at sea; but I attempted a direct solution of the problem; and, continues *M. Bouguer*, as this is entirely my own, I shall give the following account of it:

Let a ship be 163 feet in length from the stem to the stern-post, the extreme breadth 44 feet 9 inches from out to out. I found the area of the vertical section perpendicular to the keel to be about 691 square feet: This section would receive the whole impulsion of the water, supposing there was no bow; but by reason of the convexity of the bow, the impulsion will be much less; the only difficulty will be to determine how much less it will be.

In examining a small ship at *Croisic*, I found the shock of the water on the bow to be one sixth and an half of that on the plane of the vertical section. The area of that plane carefully measured was 6687 square inches; the impulsion it received 66,870,000, whereas, by dividing the bow into 18 triangles, and adding up all the particular impulsions of each triangle, the whole sum was 10,245,735, nearly the $\frac{1}{6}$ part of 66,870,000; for $10,245,735 \times \frac{6}{5} = 66,597,277.5$.

I imagine that in ships of war it will be less, and may be reduced to the ninth part, so that we may take 77 instead of 691 square feet for the area of the midship frame. But having occasion myself to visit our sea-ports, and to know the form of our great ships, I was forced to acknowledge that the shock on the bow was only one quarter, or at most one quarter and an half of that on the midship frame. This great difference betwixt the large ships, and the conoid of least resistance, is occasioned from this.

The

The conoid diminishes gradually from the extreme breadth, at the midship frame, which is its base ; whereas, in ships, the whole breadth is continued for a considerable space, and then diminishes suddenly ; which will have the same effect, as if the bow were shorter, or had less rake. In fine, according to the present form of our ships, if the area of the midship frame be 691 square feet, we may account about 150 square feet for that which receives the relative direct impulsion.

We must now consider the effort of the wind upon the sails ; the area of the three sails on the main-mast, should be about 10316 square feet, and if the wind be on the quarter, most of the sails on the fore-mast will bear a part of the impulsion, on which account we may add one half more, so we have 15474 square feet for the area of the sails that receive the shock of the wind ; which should be equal to the impulsion of the water on 150 square feet, as was before proved, to which the bow is supposed to be reduced ; besides the densities of the two fluids should be considered, for if one fluid be double or triple the density of another, or, which is the same thing, if it be double or triple the specific gravity, then the shock will have double or triple the force. Mercury, for example, with the same velocity will give an impulsion with fourteen times more force on an equal surface, than water ; because Mercury is fourteen times heavier than water, and for the same reason water will make an impulsion 576 times stronger than the wind, because as *M. Mariotte* observes, water is 576 times heavier than air, and their impulsions are as the squares of their velocities. All this being admitted, let the velocity of the ship be 100, then 150, the square feet that receives the impulsion of the water, multiplied by 576 the density of the water, and this product by 10,000, the square of the velocity, we have 864,000,000, which expresses the impulsion of the water on the bow ; and this should be equal to the impulsion of the wind on the sails, that is to 15,474 square feet ; the area of the sails multiplied by 1, the density of the air, and this product multiplied by the square of the velocity of the wind, so if we divide 864,000,000, which is the impulsion of the water by 15,474, the area of the sails, multiplied by 1, the density of the air, we shall have 55,835, the square of the velocity of the wind ; the square-root of which, is nearly 236. As this is only the velocity with which the sails are struck, we must add to that, the whole velocity of the ship, which makes the absolute velocity of the wind 336 ; hence, the velocity of the wind is to that of the ship's sailing, as 336 is to 100. It must be remarked, that if instead of 576 we take 1100 for the specific gravity of water to that of air, we shall find the velocity of the ship to that of the wind,

wind,

wind, as 100 is to 419; we shall take a mean betwixt these two, because 576 and 1100, compared to unity, are near the limits of the proportion the density of the air bears to that of the water.

From the whole, we may conclude, that the best sailing ship's go with two sevenths of the velocity of the wind; when the wind blows two or three times stronger, the impulsion will be four or nine times stronger, but the ship will sail only two or three times faster, because the impulsion of the water will be four or nine times stronger. Notwithstanding all our author has said on this subject, he tells us it cannot be strictly applied to all sorts of ships, so that the best that can be said of it is, that it may be an approximation, but seems to be of very little service in forming a ship's body; I shall therefore, only mention the heads of what he says in the following chapters, with some remarks as they occur.

Chapter II. Of the changes which the motion of the surfaces produce on the shock they receive.

The impulsion, says he, will be considerably less because the motion of the surfaces makes the fluid, as it were, loose a part of its velocity; he concludes this chapter with examining the sails of a wind-mill.

Chapter III. Of the changes which the motion of the ship will produce on the force and apparent direction of the wind.

Suppose, says he, the velocity 50 feet in one second, and the force on a foot square six pounds; the area of the sails 15,474 square feet being struck perpendicularly, will receive an impulsion of 92,844; but, supposing the angle of incidence about 19 and a half degrees, the sine of which is one third of the radius, the impulsion will thereby be diminished to the ninth part; and if, by the motion of the ship, the velocity of the wind be diminished to 25 feet in a second, that is, to half the absolute velocity, the impulsion will be four times less, and, consequently, the whole will be 36 times less, and reduced to 3863½ pounds.

It is plain our author supposes the absolute velocity of the wind, the angle the wind makes with the meridian, with the keel, and with the sails, to be given, and likewise the angle the sails make with the keel, and the angle of lee-way; hence the conclusions deduced from such uncertain *data* must be more uncertain; our readers will, therefore, we hope, excuse us for omitting the application. We shall only observe, that in calculating the angle of lee-way, he condemns the common vanes, which, he says, deceive us very much in determining the angle the wind makes with the sails, and recommends a quoit, such as children play with, as better adapted for that purpose than any other instrument hitherto invented. The principle from which he calculated the lee-way, is, supposing the angle

angle the sails make with the keel be 60 degrees, and the lee-way, at the same time, four degrees, from thence he proportions the lee-way to all the angles the sails make with the keel to 30 from 90 degrees. The experience of all mariners is sufficient to confute his theory, and, it may be presumed, the rules given in our *English* navigation books, by allowing the lee-way in proportion to the sail a ship carries, may be much more depended on, as they have been calculated from the journals of the expertest mariners; for, after all his researches, he refers to experience to find out this angle of four degrees, which he calls the lee-way; and tells us, the mariners find it by setting the ship's wake in the water. This has been the subject of his IVth chapter; and in

Chap. V. he treats of the different velocities of the ship, in different oblique courses, and from his process infers, that, in order to double the velocity of the ship's sailing, she must spread sixteen times more canvass.

The VIth and VIIth chapters contain the construction of tables to ascertain the velocity of the ship's sailing, which concludes the second section.

In the third section he considers the ship with respect to her propriety of steering well, either by means of the rudder, or of the sails.

The first chapter is upon the situation and number of masts, and on the equilibrium, which should subsist betwixt the head and after sails, out of which we shall make the following extracts.

The principle, says our author, having been already established, touching the equality and perfect opposition which should subsist betwixt the impulsion of the wind, and the impulsion of the water, we may, from thence, deduce a sure method for placing the masts. If the ship has but one mast, it must be, of necessity, in the point C, *Fig. 14*, which is the intersection of the direction of the shock of the water with the keel, in oblique courses; but if in place of one we put more masts, they must be before and abaft the point C, in Z and Y, so that the sails on each side that point be in equilibrium; it is of great importance to determine this point C. According to the ordinary form of our ships, the line of direction FC intersects the keel in about two ninths of the length from afore, or nearly five sixteenths of the whole length of the ship; that is, let BA, the length from the head of the stem to the post be 160 feet, CA will be about 50, this will not answer in all ships. If the ship be formed by two cones joined at the same base, one for the fore and the other for the after part; the fore part five twelfths and the other part seven twelfths of the whole length, and the extreme breadth one quarter of the whole length, CA will then be about $48\frac{1}{2}$ of the whole length;

length; but if the breadth DF be the sixth part of the length AB , then CA will be only the 46th part of the length.

It must be remarked that these lengths agree only to the point C in its first situation, or first oblique courses.

Without being at the trouble to find this point by calculation, it may be done by a simple experiment, on a model of two feet long, or on a ship already built, by hauling it in the harbour with a tow line fastened to one side of the bow; if this line be produced it will intersect the keel in the required point C . This point being once determined, we can place but one mast in that point, or if it be requisite to have more, they must be placed on each side in such a manner as to preserve an equilibrium betwixt the sails; for instance, if we place the mast in Y , at less than the tenth part of the length from the center of effort C , without altering the other masts, the sails must be enlarged in the same proportion the distance from the point C is diminished.

It may be demonstrated, that ships that are built on purpose for sailing should be made considerably longer, or which is the same thing narrower, at the same time the sails must be narrower; and then we may have four instead of three standing masts; it is only by experience we shall discover if the thing be practicable; but they must be so placed that the total of the moment of the head sails be equal to the total of that of the after sails, on each side of the point C : We may easily discover if the equilibrium betwixt them subsists.

The area of the main and main-top-sails of a ship of the first class is about 9500 square feet, and that of the fore and fore-top-sails, about 8040, nearly, in an inverse proportion to their distances from the point C , and multiplying each area by its distance from the point C , we have their respective moments. The distance of the main-sail from C is $32\frac{1}{2}$ $\times$ 9500 makes 306,375 its moment, and the distance of the fore-sail $38\frac{1}{2}$ $\times$ 8040 makes 309,540 the other moment.

We may without doubt narrow the ships considerably, if we be allowed to increase the number of the masts; if we have four masts the fore-mast Z must be as near as possible to the point A , the extremity of the bow, and two main-masts, one in P , if possible before the point C , and the other in Q abaft it, and likewise abaft the middle of the ship; the sails of these three will be in a perfect equilibrium, or which is the same thing, the moment of the two first will be equal to the moment of the third, observing, at the same time, to make the space PQ a little more than the space PZ , nearly in proportion, as the sum of the areas of the two main-sails is more than the sum of the areas
of

of the other main-sail and fore-sail. Lastly, the mizen-mast must always be in Y, or a little further aft. The use of the sail on this mast is to preserve the equilibrium, when the sea takes the ship on the after-post, so that the point C comes nearer the middle of the ship. The sails on the bowsprit have likewise their proper use and have a contrary effect to that of the mizen.

Our author then tells us, that if we push this to the utmost rigour, we may, instead of four, have a great many standing masts, and gives us a rule for placing them properly; but as it may be presumed this is an experiment that will scarce ever be tried, I shall omit it.

The second chapter is on the figure a ship should have in order to make her steer perfectly well with her sails, of which we here subjoin some extracts.

The only means, says our author, to attain this is to make it so that I C, *Fig. 15*, the direction of the shock of the water in the oblique courses, shall always pass thro' the center of gravity G: This has put the builders under a necessity of making the fore part full, tho' they alledge a quite contrary reason for doing it; which is, that thereby a ship will divide the fluid with a greater ease; and to prove this, they tell us that fishes are broader at the shoulders and head, than at the tail, and that a mast will tow best with the butt end foremost; these pretended reasons have gained such credit as to be adopted by several eminent mathematicians; but they do not consider that the author of nature created fishes, living creatures, with a head, stomach, &c. and it is not certain that their form is the properest for dividing a fluid, since perhaps they must lose some part of that advantage, in order to gain some other of which we are altogether ignorant. As to the mast, the only reason for towing it butt end foremost, I think, is, that the rope may not slip over the end; but, continues our author, we may reconcile the whole, by saying, that this form is proper, not to make the ship sail faster, for we are sure it will have a quite contrary effect, but to make her steer well. It happens unluckily, that we must lose a little of the first advantage to gain some of the other, and as we have not arrived at that perfection, to ballance them perfectly, because they are of different kinds, we must have recourse to experience, to discover the proper mean betwixt the two: Notwithstanding, our author seems here to think that making a ship full before should not be, because the form would thereby resemble that of fishes; yet, in *Page 59*, he tells us the midship frame should be placed at five twelfths of the length from afore, and gives for one reason, that thereby the immersed part will better imitate the

Supp.

H

figure

figure of fishes; and here, after all his laborious calculations, refers us to experience, which may possibly give it contrary to his theory.

He afterwards proposes *Noah's* ark, or the *Chinese* junks, as best formed for steering, tho' not for sailing; and, besides, they will be very subject to drive to lee-ward; and the like may be said of any other form which will make a ship steer well; and this he endeavours to prove by considering a ship formed by two cones; he chuses that figure not only to render his researches more simple, but because, he says, that figure differs little from the form of the solid of least resistance. The inference he deduces from his algebraick process, seems to be only this, that these two properties of steering well, and sailing fast, are incompatible; and, therefore, we must part with a little of the one, that we may not loose the whole of the other. I shall only remark, that the mariners have adapted a direct contrary maxim, that is, that a ship that goes well, will undoubtedly steer well, which has been confirmed to them by experience.

In the third chapter, he endeavours to determine the exact point where the extreme breadth should be placed, to render the ship more sensible of the power of the helm.

Many mechanicks, says our author, have long ago discovered, that when a power is applied to the extremity of a rod of equal weight throughout, in order to make it turn, the point of rotation will be about two thirds of the length; the rod being supposed of equal weight in all its parts; from whence our mariners infer, that the extreme breadth of the ship should likewise be two thirds from afore, without considering the case may be different. It has been the general practice to have it at that place, tho' they have by degrees drawn it nearer the middle, to render the bow sharper, and diminish the resistance; but it is certain, that, by such a change, they very much assist the action of the rudder, and herein is one of the particular circumstances, where we had better be entirely governed by experience, than by theory which continues imperfect, because it has not been pushed to a sufficient pitch; however, after a long algebraick process, he infers, that it should be placed neither at the middle, nor at two thirds, but nearly betwixt these two points, or about the twelfth part of the whole length before the middle.

In the fourth chapter is his method of knowing if the ship, that is proposed to be built, shall steer easily; or an examination of the motion which a body should take, when two powers exert their force, in contrary directions, to turn it on different sides.

The fifth chapter is only the sequel of the preceding, and, after examining the quantity and position of the sails, he concludes, that in that article, they had too much regard to the sailing, to the prejudice of her
steerage

steerage ; to remedy which, he says, we must either give the ship more head-fail, or if she is not yet framed, carry the midship frame farther forward. This ends his third section.

In the fourth section, he examines a ship with respect to the qualities best adapted to make her carry a good sail, in eight Chapters.

Chap. I. Of the mutual vertical effort formed by the united impulsions of the wind upon the sails, and the water on the bow.

Chap. II. Of the different stations of the ship, occasioned by the mutual vertical shock of the wind on the sails, and of the water on the bow ; and the conditions requisite for properly masting a ship.

Chap. III. General principles to determine the greatest height the masts may have, so as not to be in danger of being dismasted, with some remarks on the power a ship of each class has to carry sail.

Chap. IV. The sequel of the preceding ; to determine the limits of the highest mast, and the application of that rule to a ship of the first class, and the *Gazelle* frigate.

Chap. V. After answering some objections, he examines what dimensions of the sails should be enlarged ; and if proper to make the masts of a ship of different heights.

Chap. VI. To determine the most advantageous set of masts for a ship already built, the draught of water being assumed at pleasure.

Chap. VII. Of the form a ship should have in regard to her girt, best adapted to make her carry a good sail, and go fast thro' the water.

Chap. VIII. Of the girt of a ship, in respect of her length, most conducive to make her carry sail, with the means which may increase the velocity of her sailing to a very extraordinary degree.

Our author supposes the following particulars to be known, or at least attainable, by his preceding rules :

1st. The direction in which the shock of the water strikes the bow : This exerts itself in a double capacity, for it not only endeavours, by the resistance, as it were, to push her a stern, but likewise lifts up the bow ; this angle, in his calculation, he supposes to be $48^{\circ} 20'$, which the line *DH*, *Fig. 16*, makes with the horizon.

2d. The line *SK*, representing the direction of the wind on the sails, that is to say, the angle that line makes with the horizon ; for tho' the wind always moves nearly parallel to the horizon, yet the impulsion on the sails is in a perpendicular to their surface, and if we consider the whole as united in *I*, the middle of the sail, the impulsion will be in a direction, perhaps not parallel to the horizon.

3d. The whole force of the shock of the wind on the sail, which, he says, may be had by an Anemometer.

H 2

4d. The

4th. The point N, which he calls the *velique*; to determine which we are to erect a perpendicular V T to the water line, to pass thro' the center of gravity Y; the intersection of this line, with the line D H, will give the point N, thro' which S K must pass; and when the center of the effort of the wind passes thro' this point, we may, without running any risk, give the sails what extent we please; it is presumed, our author means, this should be in the middle of the main-sail, but, he says, if the mast be higher, it may be of dangerous consequence.

5th. The center of gravity of the immersed part, the center of gravity of the whole ship when loaded, and the metacenter; likewise their positions and respective distances from one another.

6th. The weight of the whole ship when loaded, and the exact draught of water. He supposes, in a first rate, the center of gravity to be two feet below the metacenter, and the center of gravity, by the inclination of the ship, to be moved four inches from the vertical passing thro' the metacenter, in which it was when the ship was upright; he likewise supposes the greatest inclination in a ship of the first rate to be $9^{\circ} 30'$. The inference deduced from these data is in page 564, that ships that are built on purpose for sailing cannot be too narrow, so their length be preserved, and asserts, that to have a ship absolutely perfect, she must be infinitely narrow, on which account she must have an infinite number of masts and sails, and, in page 566, he assures us that a frigate, which is 18 or 19 times longer than she is broad, will sail faster than the wind, and if it were permitted to reduce her to half the breadth, if then the wind strikes the sails in a perpendicular direction, the sails at the same time making an angle of $19^{\circ} 30'$ with the keel, the ship will then sail with a velocity not only equal to the wind, but with a velocity a third or fourth part greater than that of the wind. I shall not take upon me to follow him in these deep researches, but refer our readers to the original, as it is scarce possible, at least probable, that this should be ever reduced to practice, and so have the theory confirmed by experiments.

In the fifth and last section, he considers a ship, with respect to the velocity of her sailing, and the qualities necessary to make her keep a good wind, and drive but little to lee-ward in oblique courses. This takes up ten chapters.

Chap. I. An examination of the simplest figures which receive the least possible resistance from the mediums through which they move.

A table of the dimensions of an angular and rectilineal bows, in an horizontal sense, which meets with least resistance in passing through the water.

Chap. II.

Chap. II. Of the conoid bow, which meets with the least possible resistance in dividing the fluid.

A table of the dimensions of such a conoidal bow.

A table of the dimensions of a new conoid, which will meet with least resistance.

A table of the dimensions of two conoidals, which meet with little resistance, only when they are not wholly immersed.

Chap. III. A base being given, to find the figure of that solid which should cover it, so that it should meet with the least possible resistance in passing through the water.

Chap. IV. Of the formation of several other bows of least resistance.

Chap. V. Of the bow of greatest velocity, or of that which will render a ship more capable to carry sail, and at the same time will divide the fluid with greater facility.

Chap. VI. To determine the figure of the bow of greatest velocity, when it is terminated by a simple horizontal draught.

A table of the dimensions of a curvi-lineal bow of the greatest velocity.

Chap. VII. Of the figure of the after part, when it is terminated by a simple horizontal draught, and the method to be used in order to form frigates.

Chap. VIII. The sequel of the preceding; an examination of the after part, when it is a conoid, and how to form a frigate.

A table of the dimensions of the conoidal after part, which contributes to the greatest possible degree of velocity, by the impulsion it receives from the reflux of the water.

Chap. IX. Of the form of transports, and of ships of war; and of a new form for frigates.

The first solution. When the bow is formed by two vertical planes, which make an angle.

The second solution. When the bow is terminated by one inclined plane afore.

A particular method to form ships of war and frigates.

Chap. X. The sequel of the preceding: An examination of the particular form properest for the bow of a transport.

A table of the dimensions of a bow of the greatest motion, which, our author tells us, differs from that of greatest velocity in some cases.

In this last section our author observes, that it is very doubtful whether that figure which meets with the least resistance in dividing the water, may be the most advantageous to acquire the greatest degree of velocity; for it is possible that a bow, which meets with a little more resistance, may render the ship capable of carrying a proportionate quantity of more
sail;

fail ; nevertheless, the two bows, which we may distinguish, by naming the one that of the least resistance, and the other that of the greatest velocity, should have such an affinity to one another, that one should, in a great measure, partake of the most essential properties of the other.

He then proceeds, in his usual method, by an algebraic process, to investigate the form of several bows ; and, to save his readers the trouble of an intricate calculation, has constructed tables of their several dimensions, which we shall hereto subjoin and illustrate, by forming one of the curves from these dimensions, which may serve as a specimen for all the rest.

TABLE I. *Of the Dimensions of an angular and rectilinear Bow, in an horizontal Sense, which meets with least Resistance in passing through the Water.*

Height or depth	Half Br. or Ordinates	Height or depth	Half Br. or Ordinates	Height or depth	Half Br. or Ordinates	Height or depth	Half Br. or Ordinates
0	899	374	1300	778	2000	1164	2900
14	900	408	1350	826	2100	1200	3000
79	950	440	1400	873	2200	1236	3100
132	1000	471	1450	916	2300	1271	3200
180	1050	502	1500	962	2400	1306	3300
223	1100	561	1600	1004	2500	1341	3400
265	1150	619	1700	1046	2600	1376	3500
303	1200	674	1800	1086	2700	1410	3600
340	1250	728	1900	1125	2800	1444	3700

TABLE II. *Of the Dimensions of a conoidal Bow, which meets with the least possible Resistance in dividing the Fluids.*

Abscissa, or parts of the axis.	Half Br. or Ordinates.	Impulsions.	Abscissa, or parts of the axis.	Half Br. or Ordinates.	Impulsions.	Abscissa, or parts of the axis.	Half Br. or Ordinates.	Impulsions.
0	308	148993	4518	2545	1949062	41862	12040	14543335
6	317	155239	5194	2791	2189549	45383	12765	15615915
20	356	167905	5943	3053	2453469	49118	13520	16837987
44	364	186165	6769	3333	2743083	53080	14304	18132351
78	400	208184	7678	3631	3059421	57280	15119	19505003
125	444	236721	8675	3948	3404528	61727	15966	20949435
185	496	268916	9767	4284	3780198	66423	16845	22478039
260	557	307900	10959	6440	4188257	71386	17755	24089705
354	626	353607	12258	5016	4630586	76624	18699	25790519
468	704	405964	13668	5413	5109155	82139	19676	27580596
604	792	466875	15108	5832	5626246	87935	20688	29463846
766	890	536439	16852	6273	6182762	94086	21736	31444132
956	999	615734	18639	6737	6792289	100524	22817	33524478
1178	1118	705619	20565	7225	7426420	107285	23936	35708216
1434	1250	807369	22636	7736	8117090	114387	25090	38001324
1729	1394	922068	24861	8272	8867188	121835	26279	40399311
2065	1550	1050881	27246	8833	9648764	129642	27507	42913773
2448	1720	1194679	29800	9421	10493903	137820	28777	45545900
2880	1904	1355015	32531	10034	11395391	146380	30085	48208823
3366	2102	1533275	35447	10675	12355760	155334	31431	51462561
3911	2316	1730807	38555	11343	13377500	164694	32818	54183109

TABLE III. *Of the Dimensions of a new Conoid, which will meet with least Resistance.*

Abcissæ or parts of the axis.	Half area, or ordinates.	Abcissæ or parts of the axis.	Half area, or ordinates.
0	100	5143	2593
23	122	8247	3451
55	150	10261	4632
97	183	14605	6269
155	226	20909	8559
233	280	30122	11788
340	349	43619	16379
675	552	64773	22961
962	701	93780	32478
1344	896	138926	46355
1876	1155	207366	66766
2619	1501	311931	97045
3665	1969		

TABLE IV. *Of the Dimensions of two Conoidales, which meet with least Resistance only, when they are not wholly immersed.*

When the Axis of the Bow is elevated 1000 parts above the Surface of the Water.				When the axis of the Bow is elevated 2000 parts above the surface of the sea.			
Abcissæ, or parts of the axis.	Ordinates, or half Breadths.	Abcissæ, or parts of the axis.	Ordinates, or half Breadths.	Abcissæ, or parts of the axis.	Ordinates, or half Breadths.	Abcissæ, or parts of the axis.	Ordinates, or half Breadths.
0	1045	1372	1800	0	2023	3223	3400
3	1050	1854	2000	5	2030	3825	3600
21	1070	2368	2200	14	2040	4449	3800
83	1125	2910	2400	36	2060	5093	4000
150	1175	3478	2600	89	2100	5756	4200
264	1250	4069	2800	248	2200	6438	4400
347	1300	4682	3000	433	2300	7136	4600
435	1350	5969	3400	636	2400	7851	4800
527	1400	7329	3800	1082	2600	8582	5000
721	1500	8753	4200	1570	2800	9327	5200
927	1600	10239	4600	2093	3000	10859	5600
1145	1700	11781	5000	2645	3200	12446	6000

TABLE V. *Of the Dimensions of a Curvilinear Bow of the greatest Velocity.*

First Figure.				Second Figure.				Third Figure.				Fourth Figure.			
Abcissæ, or parts of the axis.	Ordinates, or half Breadths.	Moments, or stability.	Abcissæ, or parts of the axis.	Ordinates, or half Breadths.	Moments, or stability.	Abcissæ, or parts of the axis.	Ordinates, or half Breadths.	Moments, or stability.	Abcissæ, or parts of the axis.	Ordinates, or half Breadths.	Moments, or stability.	Abcissæ, or parts of the axis.	Ordinates, or half Breadths.	Moments, or stability.	Abcissæ, or parts of the axis.
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
126	203	146	0	356	169	31	0	200	65	7	0	125	31	2	0
399	531	333	9	712	335	61	4	400	129	13	0	250	62	4	0
627	714	406	46	871	402	71	10	703	225	23	1	500	122	7	0
758	788	425	83	1042	464	78	19	861	272	27	3	671	163	9	1
884	838	432	128	1136	493	81	26	1035	318	30	6	827	198	10	1
936	853	433	149	1200	510	82	31	1100	338	31	8	900	214	11	2
963	859	433	182	1272	526	84	38	1205	356	32	10	999	234	12	2
977	862	433	188	1310	533	84	42	1288	371	32	13	1174	266	14	4
987	863	433	193	1330	536	84	44	1333	379	33	14	1267	281	14	5
1001	865	433	199	1395	541	84	47	1401	387	33	17	1380	295	14	7
1014	866	433	204	1399	543	84	51	1466	391	33	19	1490	302	14	9

TABLE VI. *Of the Dimensions of the conoidal after part, which contributes to the greatest possible Degree of Velocity, by the Impulsion it receives from the Reflex of the Water.*

Abscisse, or parts of the poop.	Ordinates, or half Breaths.	Abscisse, or parts of the poop.	Ordinates, or half Breaths.	Abscisse, or parts of the poop.	Ordinates, or half Breaths.	Abscisse, or parts of the poop.	Ordinates, or half Breaths.
0	260	315	485	1538	996	4487	1831
2	262	382	521	1709	1054	4832	1914
9	271	456	559	1893	1114	5188	1998
21	283	539	600	2089	1177	5564	2084
37	299	630	642	2301	1242	5964	2174
59	317	729	686	2525	1309	6381	2265
86	339	838	732	2762	1378	6811	2358
119	364	957	781	3013	1449	7265	2454
159	390	1086	831	3278	1522	7738	2551
204	420	1225	884	3556	1596	8234	2652
256	451	1375	939	3849	1672	8750	2754
				4158	1750		

TABLE VII. *Of the Dimensions of the Bow of greatest Movement.*

Abscisse, or length of the axis on the bow	Ordinates, or the depth of the Bow.	Impul- sions.	Abscisse, or length of the axis on the bow	Ordinates, or the depth of the bow.	Impul- sions.
0	0	0	259	508	397
1	50	50	284	524	402
5	98	97	307	538	406
18	185	182	328	550	409
35	252	245	349	561	411
50	297	285	365	570	413
61	320	304	381	578	414
63	325	308	412	592	417
69	335	316	437	602	418
83	352	327	457	610	419
102	375	340	486	620	420
126	400	354	511	628	421
152	425	365	541	636	422
179	448	375	586	645	422
206	470	385	612	649	422
233	490	391	628	650	422

Our author remarks on Table I, that in joining two surfaces, A B R S, (*Fig. 17*) the bow may be formed nearly to what the figure represents, and will meet with the least possible resistance, in passing thro' the water, in a direct course, or in any oblique courses which do not exceed 45 degrees. This bow has that particular property, that it will meet with the least possible resistance, without regarding how deep it sinks into the water. It is not the curves of the ridges, A I S, and

B H R,

BHR, of which we give the abscissa and ordinates; it is of that which results from the section of the surface ABR S, cut vertically and perpendicularly to its length; the point A being the origin of the abscissa extending along DC.

On Table II. He says, we must take the value of each abscissa from a scale of equal parts, and lay it off from A to X, or to C, on the straight line AC, *Fig. 18*, beginning always at the point A; and then make the perpendiculars XV and CD equal to the corresponding ordinates in the table.

We shall now give our readers the substance of his Conclusion.

After having, to the utmost of my power, says our author, executed every part of the engagement I undertook, it will be proper now to recapitulate the principal things I have explained, especially such as relate to the figure of the ship; and I shall make no scruple again to affirm, that, I believe, I have given infallible rules to the builders, to determine their choice of the different plans that may be presented to them of the same ship. We have, in the second book, explained all that concerns a ship while afloat or at rest: We may know if the whole weight be proportional to the solidity of the immersed part; if she has stability or force to carry sail; or if she carries her guns high enough out of the water: And, in the third book, we have given proper rules to assure us she will sail well; drive but little, when close hauled upon a wind, and readily answer all the motions of the helm. All the other qualities are submitted to the proof of a calculation, which costs but little labour: Even such accidents as seem to depend on very irregular causes are considered; such as the duration of the vibrations occasioned by rowing, and those of pitching; we may judge of them by examining the distribution of the weights, and in what manner every particular weight is supported in every different circumstance.

Geometricians think no labour too hard, and do not satisfy themselves with what knowledge they have acquired, but are continually pushing their researches to the highest pitch; notwithstanding all this, we must sometimes have recourse to experiments on ships already built, which may serve as a term of comparison. By these experiments we may, in an instant, discover things which could not be done any other way, without a great deal of labour; and, in forming another ship, it may suffice to take notice of their different dimensions, and the necessary causes that may occasion some alterations.

We have endeavoured, out of an infinite number of forms, to pick out the best; and where the disposition of different parts contribute to

Supp.

I

carry

carry a certain property to a higher degree, we have searched the most advantageous combination, to determine the *maximum*. We may, with certainty, make which property we please predominate, and at the same time know how far we may carry the others.

We have shewn, that the extreme breadth should be five twelfths of the length, from the fore part, which is the position best suited to make the ship answer the motions of the helm; but it must be carried a little further forward, to make her steer well by the assistance of the sails, though, by this means, the bow will become fuller, to the prejudice of her sailing, and of that property which should make a ship less subject of driving to the leeward. It will be impossible to reconcile these four properties; and, that we may not lose too much of any one of them, we must resolve to lose a part of the others; and the surest way, in most cases, will be to embrace that which most favours the action of the rudder.

We have, in the first book, explained several methods of describing the midship frame, which may be improved by the remarks in the second and third books.

Suppose we cannot persuade ourselves to abandon the common practical rules, nor venture at once to go to the utmost point of perfection, yet it is to be wished, that the breadth and depth should bear but a very small proportion to the length; it is a matter of great importance, and merits the utmost attention of the builders. The section of the midship frame should be a triangle in light frigates, but a rectangle in ships built for burthen. In these last, the breadth is continued the same as in midships, for a considerable space, nearly the fifth part of the whole length. The common rules are very well adapted to the building of such ships, and want very little amendment, but are very deficient in the frigates, which begin to narrow, both fore and aft, from the very midship frame. The ships of war, as it were, keep a mean betwixt these two; they are ships of burthen, but their great weight is situated in a very inconvenient manner, their center of gravity being too near their metacenter; they must, on that account, and on account of carrying their metal, be broader in proportion than other ships.

The principal dimensions being established, we may form the ribbands, and so the work will be completed. We may use the method of approximation, delivered in the XIth chapter of the first section of the first book; or conform to the tables, which we have with great pains calculated, and inserted at the end of the last section, that the practical part may receive all the benefit that may accrue to it from theory.

So far M. *Bouguer*; and here follows what M. *Dubamel* has said on the center of gravity.

Abridg-

*Abridgement of what M. DUHAMEL has said in his
second Edition on the Center of Gravity.*

M. DUHAMEL in this edition, has given us an additional Chapter, wherein he explains a method to find, whether or no a ship will carry sail.

The principle on which he fixes the stability or stiffness of a ship is the proper fixing the center of gravity of the whole body, including, as well, the masts, yards, guns, &c. that are above the water, as the ammunition, ballast, &c. that are below the water; and in order to give us a distinct idea of that term, the center of gravity, he proceeds in the following manner:

It is easy to conceive that the same quantity of any matter may be put in different forms, but it will still be the same weight; for a piece of lead in form of a globe of one inch diameter, may be extended so as to cover a circle of one foot or more diameter; but it is plain the lead will be the same weight in both forms, and if it were possible to press it so as to become a globe of one eighth of an inch diameter or less, this small globe would weigh as much as the other great one; but because the parts of matter cannot penetrate into one another, this cannot be effected. Let us then suppose the whole weight of the globe A (*Fig. 20.*) to be united into one point *a*, and we shall have an idea of what in mechanicks is called the center of gravity.

The center of gravity then, of any body, is that point, whether it be within or without that body by which if it was suspended, or upon which, if it were supported, it would rest immovable in any situation, as if the weight of the whole body were united in that single point. Hence, to find the center of gravity of any body, is to find that point, upon which, if the body rested, all the other parts would be in an equilibrium. It will be necessary, first, to say something of the equilibrium; for then we shall easily explain what is to be said on the center of gravity.

In treating of the equilibrium, I shall explain the balance, because the use and construction of the balance, and of the equilibrium, are founded on the same laws.

The balance (*Fig. 21.*) consists of a beam A B, and a fulcrum or point of support C, the center on which the beam moves, and if this be the

center on which the beam rests in equilibrio, it is the center of gravity of the beam; but as this point may be considered as one of those that form a line, it may be considered as the axis of the equilibrium; that is to say, as if formed by a line passing thro' the center of gravity: If we imagine a plane crossing the beam in the point C, we shall then have an idea of the plane of the equilibrium; that is to say, of a plane in which the center of gravity is to be found.

In order to make the beam of a balance true, the arms CA and CB, must be exactly of the same length, and likewise the weight of one arm must be equal to that of the other, and the fulcrum must be applied to the center of gravity.

Let us first consider the line AB, abstracted from breadth and thickness, and, supposing all its points to be homogeneous, they will all have an equal tendency to the center of the earth; and if there be as many points betwixt C and A as there are betwixt C and B, the line will rest in equilibrio on the point C, which will point out the center of gravity for the point S on the arm AC; and the point S, on the arm BC, being equally distant from the point C, and having an equal tendency towards the center of the earth, reciprocally destroys the weight of each other; and there being, by supposition, the same number of elementary points, betwixt A and C, as betwixt B and C, each will destroy the force of its opposite, and the line will rest in equilibrio, because the line is supposed to have neither breadth nor thickness, the point C, will be in the center of gravity; but if the fulcrum be moved towards A, or towards B, it is plain the equilibrium will be broke, because there being more elementary points on the one side than on the other, there will be a preponderating force, which will cause the line to incline; so we may perceive that the center of gravity of a line, or of a rod, every where of equal thickness and breadth, and all its parts of equal weight, will be exactly in the middle of the line or rod.

It will not be amiss here to remark, that in finding the centers of gravity of lines, or surfaces, we need only consider their extent, because as the matter of which they are formed is supposed homogeneous, all the parts will be equally affected with that tendency they have towards the earth's center, or that force which makes bodies descend, affects all the parts equally.

It is easy to prove that the center of a parallelogram (*Fig. 22.*) is in N, the center of the figure; for, supposing the parallelogram to be formed by elementary lines parallel to AB, as we have already proved, that the center of gravity of a line is in the middle of it, if the line IK be
drawn

drawn thro' the centers of gravity, of the elementary lines parallel to AB , it will be the axis of the equilibrium in which the center of gravity, of the figure must certainly be found. Let us then suppose other elementary lines parallel to BD ; we shall have LM another axis of the equilibrium, in which likewise the center of gravity must be; and because the point N is the only one, common to both axes, it must be the center of gravity; hence, the center of gravity of a parallelogram must be in the center of the figure; and for the same reason the centers of gravity of circles, ellipses, of polygons, of any even number of sides, will be in the centers of the figure, as is evident by a bare inspection of the figures.

It will be as easy to find the center of gravity of any triangle (*Fig. 23.*) for, supposing it formed by the elementary lines AB , we have CD , one axis of the equilibrium; again, supposing it formed by the elementary lines EF , we have GH , the other axis of the equilibrium, so shall N , the point of their intersection, be the center of gravity of the triangle; hence, the center of gravity of any triangle will be in the point of intersection of two lines bisecting any two sides, and drawn from the angles opposite to those sides. If we suppose a regular pentagon, (*Fig. 24.*) formed by elementary lines AB , we shall have the axis DC ; again, supposing it formed by the elementary lines EF , we shall have the other axis GH , so shall N , their point of intersection, be the center of gravity of the pentagon.

As by supposing all surfaces to be formed by lines, we have discovered an easy method to find the centers of gravity of regular surfaces, so if we consider surfaces, as the elements of solids, we may as easily find the centers of gravity of solids; for if we conceive the parallelopiped, (*Fig. 25.*) to be formed by an infinite number of parallelograms, parallel to $a b$, the centers of gravity of all the parallelograms will be in the center of the figures as was before proved; and if we draw a line $c d$, thro' all the centers of gravity, we shall have the axis of the equilibrium, in which the center of gravity of the parallelopiped is to be found, and as all the parallelograms are equal, we may conclude that the center of gravity of the parallelopiped is in the middle of the axis $c d$; and, for the same reason, the centers of gravity of a cylinder, of a sphere, or of an ellipsoid, are exactly in the center of these solids.

As any prism may be considered as composed of surfaces, or thin slices equal and similar to their bases, and that a strait line drawn from the center of gravity of one base to that of its opposite, passes thro' all the elementary

elementary slices, the center of gravity of all prisms, or cylinders, will be in the middle of that line which is the axis of the equilibrium.

As to the center of gravity of a triangular pyramid, it is plain it must be in a strait line, drawn from the vertex to the center of gravity of the base; for, let the pyramid be divided into elementary slices, parallel to the base, the centers of gravity of all these surfaces will be similarly placed, and, using the same operation on all the sides of the pyramid, we shall have different axes of the equilibrium; their point of intersection, which will be one fourth of the length from the base, will be the center of gravity, and as a cone may be considered as a prism of an infinite number of sides, its center of gravity will likewise be in the one fourth of its axis from the base.

Hitherto we have considered surfaces and solids as composed of parts which are of equal weight; but if the parts are of unequal weights, the solutions will be false; for, supposing the part CB, (Fig. 26.) of the line AB to be gold, and the part CA to be iron, and the specific gravity of CB 3, and that of CA 1; the fulcrum being in the middle of the line, the part CB will raise the part CA. In this case, in order to find the fulcrum, on which it will rest in equilibrium, we need only find the center of gravity of CB; which will be in d , the middle of that line, that part being supposed homogeneous, and, for the same reason, the center of gravity of CA, will be in e , the middle of the line CA. Let us now consider the whole weight of the line CB, united in d , and the whole weight of the line CA, united in the point e ; all that remains to be done, is to find the center of gravity of two bodies (Fig. 27.) the weight of d being 3, and that of e 1 pound. In order to solve this problem, let the two bodies be joined by a rod that will not bend, and as the two bodies together weigh 4, divide the rod de into four equal parts, so shall the center of gravity C, be in the third division from E, (Fig. 28); for the weight d , multiplied by the arm BC, will be equal to the weight e , multiplied by the arm AC. The arm of the lever AC, is to the arm BC as d to e ; we shall explain this by an example taken from the common balance. Let AB (Fig. 29.) represent the beam of a good balance, four feet long, C the fulcrum; now as AC and BC are exactly the same length, that is, two feet each, and of equal weight; the beam will rest in equilibrium on the fulcrum C: If we suspend to the extremities of the beam, the weights D and E of one pound each, the beam will still continue in equilibrium, because the weight D of one pound is to the lever CB of two feet, as the weight E of 1 pound is to the arm CA of 2 feet: But suppose E 2 pound, and D 1, and placed as before, it is

it is plain, the beam AB will incline to the side on which D is placed, because the weights are not reciprocally proportional to their distances from the fulcrum; and, in order to regain the equilibrium, we must shorten the arm of the beam CB , in the same proportion the weight E is augmented; so placing the weight E (*Fig. 30.*) at the point F , the two weights will then be in equilibrio; for now the weights will be reciprocally proportional to the lengths of the arms of the lever. Since $D = 1\text{ lb} \times AC = 2\text{ feet}$; $E = 2\text{ lb} \times CF = 1\text{ foot} = 2$; which may be proved by experiment.

This may be demonstrated after another manner; for, supposing the weights suspended to the extremity of the beam, if they be equal, as in *Fig. 31*, the fulcrum must be at the point C , the middle of the beam; but if E be double the weight of D , then must the fulcrum be in the point F , two thirds of the beam from the end A ; and then $D : BF :: E : AF$. Supposing then P , (*Fig. 32.*) to be 4 pounds, and R 12 pounds, and one suspended to each arm of the beam; in order to find the fulcrum, say, as 16, the sum of both the weights, is to 12, the greatest weight, so is MN , 8 feet, the length of the whole beam, to MF 6 feet, the distance of the fulcrum from M . Then $P : FN :: R : FM$.

Hence we discover a remarkable property in the lever; for in moving the fulcrum from C to F , (*Fig. 31.*) neither the absolute weight of the mass D , nor that of the arm of the lever AF , is augmented, since the beam is supposed to have no weight: And, to try this by an experiment, let there be as much weight added to B , as will occasion the beam to be in equilibrio on the point F , before we put on the weights E and D ; nevertheless, the small weight will resist the action of the great one. So the relative force of D , in respect of E , is augmented in varying the velocity; for if we put the lever in motion on the fulcrum F , we shall perceive that in the time B describes an arch, suppose of 1 foot, A will describe an arch of 3 feet: Hence we may say, with *Des Cartes*, that it will take as much force to move ten pounds with 20 degrees of velocity, as to move twenty pounds weight with 10 degrees of velocity.

Let us endeavour to make this still plainer. If the two bodies, A and B , are of different weights, their center of gravity (or the fulcrum on which the rod ED , that joins them, will rest immovable) will not be in the middle of the line; this will appear very plain, only by observing what will happen to the beam, when there is more weight in one scale than in the other.

In order then to find the fulcrum F , on which the beam shall rest in equilibrio, let us suppose it already found, and that E is double the weight

weight of D; it is evident, that E cannot have the least motion, without giving D a motion at the same time; and the two bodies will continue in equilibrio till both are put in motion.

It is not then necessary, that the two bodies be of equal weight to preserve the equilibrium; but it will be necessary, that D have the same difficulty in moving that E has; and, because E is supposed double the weight of D, it must take double the purchase to move it: Hence it follows, that the same force which will make E run over one degree, will, in the same space of time, make D run over two degrees, provided E be double the weight of D; but if triple the weight, it will run over three degrees, and *c* as *m*, (*Fig. 31.*) for the effect is always proportional to the cause. Hence this natural consequence; if the motion of D be double or triple that of E, its relative weight will be double or triple its real; and if the motion of D be triple that of E, the equilibrium will be preserved, although D be only one third of the weight of E. Now, if it be observed, that the fulcrum F, is three times the distance from A that it is from B, and that the arches of circles are in proportion to their radii; the arch, described by the point A, with the radius FA, will be thrice the arch described, by the point B, with the radius FB, in the same space of time, just as the weight of E is triple that of D. Hence, to keep two bodies in equilibrio, their distances from their common center of gravity must be reciprocally proportional to their weights. $D:E::FB:FA$.

We have made this digression, to shew the difference betwixt the absolute and relative force of any body, which will assist us to understand the nature of *momenta*, which shall be treated of hereafter: We shall here shew how to find the centers of gravity of a system of bodies of different weights, supposing them joined by an inflexible rod, passing through all the centers of gravity, the rod being conceived without any weight.

Let us then suppose the inflexible rod AB (*Fig. 33.*) passing through the centers of gravity of the several bodies *a, b, c, d, e, f*, whose absolute weights are different; first find the center of gravity of two, as of *a* and *b*, which will be in *g*, if we make *ga* (the distance of *a* from the center of gravity) to *gb* (the distance of *b* from the center of gravity) as the weight of *b* is to that of *a*: Then considering *ab* as united in *g*, let us find the center of gravity of *g* and *c*, which suppose in *b*, and then consider the weights *a, b*, and *c*, as united in *b*; and then using the same process, on the other side, we shall find the center of gravity of *e* and *f* in the point *i*; and considering *e* and *f* as united in *i*, we may find

find the center of gravity of e and d , which suppose in l . Now, the sum of the weights a , b , and c , being united in k , and the sum of the weights e and f united in l , we need only find the center of gravity of b and l , which will be the center of gravity of the whole system, composed of the bodies a , b , c , d , e , f ; and if the center of gravity be at m , there must be the fulcrum, on which the whole system will rest in equilibrium; just as if a , b , and c , were put into one scale, suspended on the point b , and d , e , and f , put into another scale, suspended by the point l , they would be in equilibrium, provided m were the fulcrum on which the beam rests; because $b m$ is to $l m$, as d, e, f , placed in l , is to a, b, c , placed in b .

It is very plain, that if the bodies a , b , c , and d , e , f , (Fig. 34.) were placed in the same plane, on different sides of the axis of the equilibrium $A B$, they would remain in equilibrium upon that axis, provided their several weights be the same as in the preceding: The distance of each body from the axis $A B$, will be equal to the distance of each body from the center of gravity m (Fig. 33.), that is, $A a$, $b M$, $c N$, (Fig. 34.) equal to $a m$, $b m$, $c m$, (Fig. 35.) and $P B$, $e P$, and $d O$, equal to $f m$, $e m$, and $d m$.

It is likewise plain, that if in a system of bodies on the line $A B$, (Fig. 33.) their center of gravity m be in one of the bodies, it may be reckoned as a cypher, in regard to the center of gravity of the whole system; though its particular weight adds to the weight of the whole system.

Though my intention here is to confine myself to treat of the center of gravity, so far as is necessary to give my readers a clear understanding of the method of finding it in ships, yet I cannot allow myself to omit shewing how to find the center of gravity, of any number of bodies placed at random in the same plane; suppose a , b , c , d . (Fig. 35.)

The center of gravity of each particular body, (supposed to be known;) we must first find the center of gravity of a and b , joined by an inflexible rod, by the foregoing method, which suppose in e ; and then considering a and b as united in e , find the center of gravity of e and d , suppose in f ; lastly, considering a , b , and d , as united in f , we need only find the center of gravity of f and c , which suppose in g , so shall g be the center of gravity of the whole system. I shall conclude this subject, with some remarks on what has been said.

I. The center of gravity of any system of bodies, may be found without knowing the dimensions of their bulk, if their weights be known; for supposing a and b to be of different matter, (Fig. 36.) the one of
Supp. K stone,

stone, and the other of wood, and each to weigh one pound, their center of gravity will be in e , the middle of the beam ab .

II. If the bodies be homogeneous, and of the same specifick gravity, their centers of gravity may be found by their bulks, without knowing their weights; for, let the two bodies a and b , (*Fig. 37.*) be homogeneous, and let b be double the bulk of a , then will their center of gravity be in e , two thirds of the length of the beam de ; and this is found without having any regard to their weight, ~~for~~ d e being double ce ; then $a : b :: ce : cd$.

III. As the center of gravity of any system of bodies, considered, abstracted from any weight, may be found by their bulks; it is in this sense, that the centers of gravity of lines, surfaces, or of any space whose weight is not considered, are said to be found.

IV. We may likewise perceive that the center of gravity of any surface, limited by strait lines, may be found by reducing them to parallelograms, triangles, or any other regular figures, whose centers of gravity may be found by the preceding rules; we may then suppose an inflexible rod passing thro' these centers of gravity, and the center of gravity of the system a, b, c , it may be found as in (*Fig. 35.*).

It will be the same with respect of solids; for every solid may be divided into parallelopipeds, prisms, cones, or triangular pyramids, and by forming another system by the centers of gravity of the several bodies, we may find the center of gravity of the whole system by the rules already delivered.

We may now perceive how the center of gravity of a ship may be found; for as the two sides A and B , (*Fig. 38.*) are equal and similar, it follows that the center of gravity must be in a plane erected perpendicular to the keel, which will be in the plane of the equilibrium of the ship, and tho' ship's bodies are very irregular figures, they may be reduced, nearly, to regular ones, by dividing them into several small parts, and the center of gravity of each may be found as before; but as this method would be too tedious for practice. I shall therefore attempt to shew how it may be performed by *M. Bouguer's* method of *momenta*.

The *momentum* of any heavy body, or of any extent considered as a heavy body, is the product of that weight, or of that extent multiplied by the distance of its center of gravity from a certain point assumed at pleasure, which is called the center of the *momentum*, or from a line which is called the axis of the *momentum*.

In order to comprehend this, it must be remembered that we made a distinction betwixt the relative and absolute weight of any body; the relative

relative weight of any body considered with respect to that of any other body, or, with respect to a point, is augmented or diminished in proportion to the distance of that body, from the fulcrum, the absolute weight remaining still unvariable ; or it is the relative weight which mathematicians consider, when they use the *momenta*, by multiplying the weight, or extent of any body, by the distance of its center of gravity from a point or line assumed at pleasure.

Example. Let B, (Fig. 39) be 6 pounds, A the center of the *momentum* of B ; and let A B be 4, then shall 24 be the *momentum* of B, relative to A. Again, let B be 6 pounds, (Fig. 40.) A B 4, as before ; 24 will still be the *momentum* ; let C likewise be 6 pounds, and A C 3, so its *momentum* will be 18, and the *momentum* of the two bodies will be 42.

If the two bodies in the same plane are not in the same direction, from the point A, that will make no alteration, if we consider them relatively to an axis A A, its *momentum* will be 24, and the distance of C being 3, from the axis A A, and weight 6 pounds, its *momentum* will be 18, so shall the *momentum* of the two be 42 as before. I said the center, or axis of the *momentum* may be placed at pleasure ; so it may be placed betwixt two bodies ; if then it may be at the point A, (Fig. 42.) precisely betwixt the two bodies B and C, suppose 6 pounds each, the *momenta*, of each being 12, they will be equal, and the center of the *momentum* will be in the center of gravity of the two bodies ; but if we place the center of the *momentum* in D, the *momentum* of C being $6 \times 3 = 18$, and that of B $6 \times 1 = 6$, the equilibrium will be destroyed.

We may now begin to perceive the relation betwixt the center of gravity and the center of the *momenta*, but to make this still plainer, we shall shew that the sum of the *momenta* of all the bodies that compose a system is equal to the *momentum* of all the bodies considered as united in their common center of gravity.

If we multiply all the weights 6, 5, 8, 4, 10, &c. which are placed along the beam A B, (Fig. 43.) by the distance of the center of gravity of each, from the point A, which is assumed as the center of their *momenta* ; that is, $6 \times 1 + 5 \times 2 + 8 \times 3$, &c. and, lastly, 6×11 the sum of all these products, will be 396 ; on the other hand, if we add the weights of all these bodies into one sum, that is, $6 + 5 + 8 + 4$, &c. + 6, the whole will be 66 ; and this multiplied by 6, the distance of the point C, the center of gravity of the system from A, the center of their *momenta*, we shall have 396 for the *momentum* of the sum of all the weights as united in C, the center of gravity of the whole system, equal to the sum of all the *momenta* of the bodies taken separately ; and

K 2

that

that it will always be so is evident, for, since the point C is the center of gravity of the whole system, in which all the weights are supposed to be united, and the point itself so placed, in respect of A, that all the weights placed betwixt C and B gain as much energy or force, by their distance from the point A, as the weights, placed betwixt C and A, loose of their particular relative force.

Hence, the *momentum* of the center of gravity, of a system of heavy bodies, is equal to the sum of the *momenta* of the several particular bodies that form the system; but it will be proper to remark, that if we consider the *momenta* of a system, with respect to a point A, which happens to be in the center of gravity of one of the extreme bodies, (Fig. 44.) it will make no alteration in the operation, only omitting that body which may be deemed a cypher; for, supposing the body A 6 pounds, then $5 \times 1 + 8 \times 2 + 4 \times 3 + 41 \times 5 + 9 \times 6 = 292$, and $6 + 5 + 8 + 4 + 41 + 9 = 73$, which, multiplied by 4, the distance of the center of gravity of the system from A, the product will be 292, equal to the former.

Let the bodies be the same weight, and placed as before, and D, the center of the *momenta* (Fig. 45.), be betwixt two of the bodies, the sum of the weights, 8, 4, 41, 9, 6, 5, multiplied by their distance from D, which is supposed the center of the *momenta*, will be equal to the sum of all the weights 6, 5, 8, 4, 41, 9, multiplied by the distance of their center of gravity C, from D, the center of their *momenta*; observing to subtract the product of the weights of those on one side of the point D, from those on the other side, because each endeavouring to turn the beam to its own side, they will have contrary effects.

Supposing D to be exactly in the middle betwixt 5 and 8; we have $8 \times 5 = 4 + 4 \times 1.5 = 6 + 41 \times 3.5 = 143.5 + 9 \times 4.5 = 40.5$, the sum of the whole is 194; and on the other side $5 \times .5 = 2.5 + 6 \times 1.5 = 9$, their sum 11.5 subtracted from 194 remains 182.5, exactly equal to the sum of all the weights $8 + 4 + 41 + 9 + 5 + 6 = 73$, which, multiplied by 2.5, the distance of their center of gravity C, from D, the center of their *momenta*, is 182.5; but it must be observed, in this last, we take the sum of all the weights, without subtracting those on the one side from those on the other, because they all tend towards the center of the earth; whereas, in finding the *momentum* of each particular body, they being suspended on different sides, their effects will be in a reciprocal proportion to their distances.

Lastly, suppose the center of the *momenta* be in E, (Fig. 46.) it is plain E equal 8 can have no *momentum*, because its distance from the center

center is o ; $E \times o = 0$, and then multiplying 4, 41, 9, by their respective distances from E , and, from the sum of their product, subtracting the product of the sum of 5 and 6, multiplied by their respective distances from E ; subtracting, I say, this product from the sum of the other products, the remainder will be equal to the sum of all the weights, multiplied by the distance of their common center of gravity C , from E , the center of the *momenta*. Having thus proved that the sum of all the particular *momenta* that compose a system are equal to the product of the sum of all the weights, multiplied by the distance of their center of gravity, from the center of the *momenta*, it will thence follow, that, if the sum of all the *momenta* be divided by the sum of all the weights, the quotient will give the distance of the center of gravity from the center of the *momenta*; or, which is the same thing, if the *momenta* of several bodies, in respect of a point or line, be divided by the weight of these bodies, the quotient will be the distance of their center of gravity from that point or line which was assumed for the center of their *momenta*.

As for example, if it were required to find the distance of C , the center of gravity of the system, (Fig. 47.) from A the center of the *momenta*; the sum of the *momenta* is 292, this divided by 73, the sum of the weights, the quotient 4 is the distance from A to C .

As examples taken from things of common use are most instructive, I shall shew that the construction of the steel-yards is founded on the same principles; but let it be observed, that we have no regard to the weight of the beam AB , (Fig. 48.) or we suppose that the part AC , of the beam is in equilibrium with the part BC , C being supposed the fulcrum on which the beam rests; we likewise suppose the distances AC , Ce , ef , fg , bi , ik , kl , lm , to be equal; and that the weight e , is one pound.

Is is plain, if we put the weight e in E , we must put one pound in D , to gain the equilibrium; but if e be put in f , we must put 2 pounds in D , because the *momentum* of e placed in f , is 2; and for the same reason, if e be put in g , we must put 3 pounds in D ; if in b , 4 pounds; if in i , 5 pounds; if in k , 6; if in l , 7 pounds; and, if in m , 8 pounds; for e equal 1 pound multiplied by m , equal 8, is equal to D 8 pounds multiplied by AC equal 1.

Supposing the points E , f , g , b , i , k , l , and m , had a weight of one pound suspended to each, these weights being all equal, and equally distant from one another; and supposing C , the center of their *momentum*, we shall have their sum by taking E once, f twice, g three, and m eight times,

times, their sum will be 36, which, divided by 8, the quotient 4.5, gives the center of gravity of the system C B.

Now we have got an easy method of finding the center of gravity of a system of heavy bodies. Thus, since the centers of gravity of a system of heavy bodies, or of surfaces, or of solids, will be in the same place, and when we know the absolute weight, or the extent of each of these bodies or surfaces, and the distance of each center of gravity from a certain point, assumed for the center of the *momentum*, or from a line, which is supposed the axis of the equilibrium, we may always find the distance of the center of gravity from that point which we have chose for the center of the *momenta*, or from that line which we regard as their axis. It is from these principles that M. *Bouguer* has furnished the builders with an easy method of finding the center of gravity of shipping.

It now remains to apply these principles, which we have established, to the finding of the center of gravity of a ship, and to begin with the simplest operations, we only propose at first to find the center of gravity of the area of a section of a ship taken at the load water line, which is represented in (*Fig. 49*) by A B.

I. The two sides of a ship being equal and similar, the line A B may be considered as the axis of the equilibrium, in which the center of gravity of that surface is to be found.

II. The curves that form the sides of that surface, being very irregular, must be reduced as near as possible to regular ones, by dividing the surface, with the ordinates *a a*, *b b*, *c c*, *d d*, observing to place them at equal distances from one another, and likewise the distances must be so small, that the portion of the curves intercepted betwixt them may be considered as strait lines, which will be near enough for practice, as we do not here propose the utmost degree of exactness.

III. These ordinates will divide the surface A, into a number of parallelograms, such as *b d*, *d b*, which may be considered as such, on account of their being so very small, it is plain, the center of gravity of the parallelogram *b d*, *d b*, is at the point where the line *c c* intersects the line A B; and it will be so with all the rest, so the centers of gravity of all the parallelograms will form a system distributed on the line A B.

IV. To find the center of gravity of the system, in respect of A, which is assumed for the first term of the *momenta*; we must, as was before observed, multiply the surface of each parallelogram by the distance of its center of gravity from the point A, and so, having the sum of all the *momenta*, we may divide that sum, by the sum of the surfaces of all the parallelograms, or by the whole surface A B, and the quotient will be the

the distance of the center of gravity from the point A, the axis of the *momenta*.

M. *Bouguer* has abbreviated this operation ; for, considering that we must have the area of the whole surface AB, before we can obtain a solution, he finds that by the method delivered in Chap. VIII. of the Appendix, which is as follows :

1st. Divide the whole length in several equal parts *aa, bb, cc, dd, &c.*

2d. Measure all the ordinates *aa, bb, cc, dd, &c.* and add them altogether except the first and the last, of which we must only take one half of each.

3d. Multiply that sum by the distance betwixt the ordinates, and the product will be the area of the section AB.

The second thing to be had is the sum of the *momenta* of all the elementary parts of the surface, which M. *Bouguer* has readily done, by multiplying each ordinate into its distance, from the point A ; then he takes the sum of all these products, except the first and last, of which he takes only one half of each ; and by multiplying that sum by the distance betwixt the ordinates, he has the sum of all the *momenta* of the elementary parts of the surface, which he divides by the area of the surface, before found ; the quotient gives the distance of the center of gravity of the whole surface from the point A.

To explain this by an example, let it be required to find the center of gravity of a surface AB (*Fig. 50.*) 160 feet long, in order to which :

1st. Divide the surface by the ordinates *ab, cd, ef*, which are here 20 feet distant from one another.

2d. Omitting the line A, which here represents one of the transoms, because we assume it for the axis of the *momenta*. It is 18 feet long.

Ordinates.	feet.	in.	lines.	Distant from A.	Product.
$\frac{1}{2}$ A 18, 9					feet.
<i>ab</i>	23	0	0	x 1	23
<i>cd</i>	28	0	0	x 2	56
<i>ef</i>	30	0	0	x 3	90
<i>gb</i>	31	0	0	x 4	124
<i>ik</i>	30	0	0	x 5	150
<i>lm</i>	28	0	0	x 6	168
<i>no</i>	21	0	0	x 7	147
$\frac{1}{2}$ B	0	6	0	x 8	4
Sum of all the Products					762
Distance betwixt the ordinates					20
Sum of the ordinates					f. in. lines.
				200) 15240 (76 : 0 : 3 $\frac{1}{2}$	Suppose

Suppose then we find the centers of gravity, of the surface of each section contained betwixt the load water line and the keel; by the same method, we shall then have a system of heavy bodies, which will have their centers of gravity in a plane erected perpendicular to the keel at their several distances from the line A B, which is assumed for the axis of the *momenta*. In order then to find the position of the center of gravity of the hull, in respect to the length, we must find the position of the center of gravity of the system, with respect to the line A B, which we assume for the axis of the *momenta*, or for the first term. (Fig. 51.)

Having by the preceding operations found the area of each water-line, and its center of gravity, we need only multiply the area of each section by the distance of its center of gravity from the line A B, and add all the products, except that of the first and last, of which we must only take one half of each, and then divide the sum of all the products, by the sum of all the areas, observing to take only half the first and last, and the quotient will give the distance of the center of gravity of the whole system from the line A B, the axis of the *momenta*; we shall explain this, by the following example:

	Areas of surfaces.		Centers of gravity from A B.	Products.
$\frac{1}{2}$ A	2000	x	76	76000
C	1800	x	82	147600
D	1000	x	90	90000
E	3700	x	80	56000
F	400	x	70	28000
$\frac{1}{2}$ Keel	55	x	80	4400
	4955			402000
				f. in. lines.
				) 402000 (81 1 6

Having divided 402000, the sum of the *momenta*, by 4955, the sum of the surfaces, we have 81 feet $1\frac{1}{2}$ inches, the distance of the center of gravity of the system from the vertical line A B, which will be nearly in the line H H.

It yet remains to find at what height above the keel in the line H H, the center of gravity of the hulk, or of the submerged part of the ship, will be found: In order to which, let us take G g, the upper side of the keel for the axis of the *momenta*, or the first term; then it is only finding the *momentum* of each surface with respect to the keel; (the distances betwixt each section being supposed 4 feet,) and then dividing the sum of all the products by 4955, the sum of all the surfaces.

Sur-

Surfaces.				
<i>f f</i>	400	x	1	400
<i>e e</i>	700	x	2	1400
<i>d d</i>	1000	x	3	3000
<i>c c</i>	1800	x	4	7200
<i>a a</i>	2000	x	2 $\frac{1}{2}$	5000
				17000

Distance betwixt $\frac{4}{4}$ f. in. lines.

4955) 68000 (13 8 2 is the distance

of the center of gravity of the hull above the keel, which will intersect the line *H H* in the point *I*.

In the preceding calculations we have supposed the hull to be composed of an homogeneous matter, all parts of which, in bulk, will be of equal weight; now, tho' this is a case that can never happen in a ship, which contains various things of different weights, yet it may not be altogether useless to the builders, since all ships of the same rate having the different weights placed nearly similar to their lengths, they may find the center of gravity as above, and comparing it with the center of gravity of a ship, which is known by experience to have all the good qualities that can be expected, we may discover if the center of gravity of the ship we are to build be properly placed, and besides it will assist us to understand what follows.

It would be a very complicated and laborious task to find the center of gravity of a ship properly masted and rigged with all her provisions and furniture on board, and, tho' I do not design to engage in the solution of that point, I think it would be unpardonable in me not to mention the action of a heavy body upon the fluid that supports it, and the re-action of the fluid on the floating body.

It was observed, in the beginning of this chapter, that the whole weight of any body may be considered as united in its center of gravity, and that if it were suspended by a line fastened to its center of gravity, that line would rest in a vertical position, and its direction would pass thro' the center of gravity, and the center of the earth; but a body which floats in a fluid is not supported by its center of gravity, but by the pressure of the environing filaments of water, which being considered as infinitely small, each will act upon an infinitely small portion of the surface of the floating body, relative to the specifick gravity, and, in proportion to the height of these filaments, conform to a principle applicable to all fluids; namely, that the weight of a column of any fluid will be in proportion

Supp.

L

tion

tion to the specifick gravity of the fluid, and the height of the column multiplied by its base.

The pressure of the fluid acting upon all the submerged parts of the solid body, in the same manner that gravity acts upon all the parts of matter, the effect of such pressure will be united in a sphere of wax, of the same specifick gravity with the fluid, and which is intirely submerged, precisely to the same point as the center of gravity of the sphere of wax; we must then conceive that the pressure of the fluid acts immediately on the surface of the submerged body; but its action is united in its center of gravity, just as if it exerted itself upon every part of the solid body. Wax is nearly the same weight with water, and if one sinks a sphere or ball of that matter, its pressure on the fluid will be united precisely in its center, or in the same point in which the whole weight of the ball does act; so in that supposition the center of the pressure of the fluid coincides with the center of gravity, the action of each being united in the center of the sphere.

But this is not all; for as heavy bodies, by their gravity, endeavour to approach the center of the earth, in a vertical line passing thro' their center of gravity, tending directly towards the center of the earth; so the pressure of fluids endeavours to carry bodies in a vertical tending from the center of the earth towards their surface, and passing thro' the center of gravity of the submerged part which forces them towards the surface; so in any submerged body at rest, these two opposite forces coincide in the same vertical, acting in a quite contrary direction to one another.

We must conceive then all heavy bodies endeavouring to approach the center of the earth, by a secret force inherent to all the parts of matter; so, (*Fig. 52.*) the globe of lead *b* tends towards the center of the earth in a vertical stretching from the point of suspension *a*, thro' the center of gravity of *b*.

Those bodies that weigh less than a column of water, (of the same bulk), in which they swim, endeavour to rise by the pressure of the fluid in a vertical line tending from the center of the earth to the center of gravity of the submerged body; so the globe of cork *d* tends towards the surface in a vertical line stretched from the point *c*, to which it is fastened to the center of gravity of the body *d*.

Let us then suppose two hooks *a* and *c* fastened to the opposite bases of the glass cylinder *A, B, C, D*, full of water, and let a ball of lead be suspended by a hair to the hook *a*, and one of cork, fastened by another hair to the hook *c*; it is plain, if the cylinder be upright, the ball of lead will descend towards *c*, with a force equal to its weight, lessened

by

by the weight of the fluid it displaces, and the ball of cork will rise with a force equal to the weight of water it displaces, lessened by the weight of the cork, and if the hair that fastens them be cut, they will be affected by contrary forces, b descending in the vertical ac , and d ascending in the vertical ca , they will meet in the same point c , of the axis of the cylinder $ABCD$. But if we suppose the cylinder inclined as in (*Fig. 53.*) each body will take a different vertical, but parallel to one another; so that if both were let loose, b would descend towards f , and d ascend towards g , and never meet. Let us suppose them joined by a rod b, e, d , of the same weight with water; it is plain that each body will obey the force that acts upon it, b describing the arch bg , and d describing the arch db , they will place themselves in the same vertical, parallel to af , or cg ; and if the force which the pressure of the water exerts on d , be greater than the force of gravity exerting on b ; then will d draw b towards the surface of the water. On the contrary, if the force of gravity, acting upon b , be greater than the force of the pressure of the water, acting on d , then will b draw it towards the bottom: But if the forces be equal, b and d will rest in the middle of the fluid in the same vertical.

The two bodies will then turn round a point in the rod b, e, d ; but it will not be easy to assign that particular place; it appears that if b endeavours to descend with a greater force than d to ascend, in that case the center of rotation will be nearest to d , and, on the contrary, if the force that raises d be greater than that which depresses b , it will be nearest to b . Hence, in all heavy floating bodies which are at rest, the center where the effect of the gravity of the body is united, and the center where the effect of the pressure of the water is united, are in the same vertical, tho' seldom in the same point, as in a globe of wax which was supposed to be of the same specific gravity with water.

In order to apply these principles to shipping, let us examine what would happen to a stick, sunk endways perpendicularly into the standing water. Now this stick (*Fig. 54.*) being supposed all homogeneous, its center of gravity in air would be in e , the middle of the stick; let us suppose the stick so light that it sinks perpendicularly only to d , the one fourth of the length ab : Now the stick being an homogeneous cylinder, the center, where the whole force of the column of water displaced is united, will be in e , the middle of the submerged part.

Now, admitting all these suppositions, it is plain, when the stick is in a vertical position, the two opposite forces acting in the same vertical line will destroy each other, and the stick will rest in that vertical position; but if the stick be but a little inclined as in (*Fig. 55.*) the case will be

be quite otherwise; for the gravity which resides in the point c , exerting itself in the direction cg , it will concur with the pressure of the water acting in the direction of the line ef to overturn the stick, or place it horizontally on the surface of the water.

The center of gravity of the stick will always be in the middle of it, at the point c , because it never changes its position with respect to the stick (*Fig. 56.*) and the center of the pressure of the water will always be in the middle of the submerged part, or rather of that space which is abandoned by the mass of water displaced, which will be in the point e , in the same vertical with the center of gravity of the stick, and so the whole will be at rest.

Let us alter some of these suppositions, and we shall find the same causes produce different effects.

Suppose then (*Fig. 57.*) the part ac , of the stick ab , to be, if you please, three times the weight of cb , of the same stick; the center of gravity of the stick in air will then be towards d ; the stick being nearly of the same weight with the column of water displaced, will sink, suppose to e , the center of the impression of the water will be pretty near to d ; but supposing it in c , or in any other point not below d , it is plain, when the stick is inclined, as in *Fig. 58*, it will return to the vertical position; for the force of gravity which acts in the direction of the line dg , will draw the end a towards i , and will concur with the force that results from the pressure of the water in the direction of the line ef , to bring the stick into its vertical position.

To make this still plainer, let us incline the stick a little more; we may easily perceive, in *Fig. 59*, that if one purchase be applied to g , acting in the direction of the line gd , and another purchase applied to f , acting in the direction of the line ef , the extremity b would approach to h , and the extremity a to i , and the stick would be in the vertical hi .

We may conclude, from this experiment, that any floating body will recover its vertical position, when the center of gravity is below the point where the force of the pressure of water is united. The stability will be diminished, if the center of gravity be never so little above the center of pressure; and the body will overturn, when the center of gravity is raised to a certain height above the center of pressure; for, in this last case, both act in concert to overturn the body; whereas, in the first, both join to preserve its upright position.

It was before observed, that the point shifts, on which the points c and d are turned round. We shall now remark, First, That this will be according as the force of c or d predominates. Second, According to the

the position of *c* and *d* upon the stick *a b*. Third, According to the difficulty that *a* will find in displacing the fluid, to bring itself to *i*, or that *b* will find in bringing itself to *h*; and it is possible, it may vary according to the different inclinations of the stick. If this point of rotation were invariable, and a method of finding it could be obtained, we might then, without regarding the pressure of the water, know where to place the center of gravity, either to keep the stick upright or horizontal. I shall explain this by an experiment, which may be made by a well-known toy, or play-thing for children.

Every one has seen (*Fig. 60.*) the small ivory puppet, which keeps itself in a vertical position, upon the point of a needle, by the assistance of two counter weights, *c* and *d*, which being joined together by a wire, are placed a good way below the pivot that supports the figure.

The weight of the figure is esteemed as nothing, when compared with the weights *c* and *d*; so the center of gravity of *c* and *d* will be towards *m*. If the figure is inclined towards *i*, the weight *c* will be carried towards *e*, and the weight *d* towards *f*; so the center of gravity will shift towards *n*; and as it strives to approach the center of the earth, and place itself in the vertical *m b*, the figure will recover its first situation. It is evident, that it will be quite otherwise, if the weights *c* and *d* are placed above the pivot, which supports the figure; for if they are placed in *i* and *k*, and the figure be inclined never so little, they will both act in concert to overturn the figure. We may likewise see, that if they are placed in *g* and *h*, at the extremities of the plane of the pivot, which is supposed to be their center of gravity, they will not, in the least, contribute to keep the figure upright.

From this experiment we may infer, First, In order to keep the figure upright, the two weights, *c* and *d*, must be exactly equal, or their difference adjusted by their distance from the line *b m*, so that their center of gravity may be in that line *b m*. Second, It will be necessary, that the counter weights be below the axis of rotation of the whole system. Third, The further the weights are below the axis *g b*, or the point *b*, the greater power will they have to recover the vertical position of the figure. Fourth, The nearer the weights are to the point *b*, or line *g b*, the less will be their power to recover the vertical position of the figure; and they have no power at all when the weights are placed in the line *g b*. Fifth, When they are placed above the pivot, they will both contribute to overturn the figure; and the greater their distance above the figure, the greater their force to overturn the figure. In order then to keep

keep the figure in an equilibrium, the center of gravity of the counter weights must be placed below the extremity of the pivot.

This important point, which M. *Bouguer* calls the metacenter, might easily be found in floating bodies, if the center of their motion were invariable and known.

It is not my intention to follow M. *Bouguer* through the various steps of his elegant investigation of this point. We shall here observe, that there is a great difference betwixt M. *Bouguer's* metacenter and the point of rotation of floating bodies. Though, in *Fig. 60*, they be exactly the same, yet in floating bodies it will be quite otherwise; and it is possible the point of rotation may be continually shifting, from the time the body begins its vibrations till it arrives at such a state as renders them regular; but it is not so with regard to the metacenter, as M. *Bouguer* has proved beyond dispute; and *c* is certainly the metacenter, in *Fig. 61*, for the sub-merged part is supposed perfectly round.

In order to apply what has been said to shipping, let us examine the case of a cylinder (*Fig. 62.*) lying in the water, of which let *abd* be a section perpendicular to the axis; let *ebf* represent the hold, which contains the ballast, &c. *ea* and *df* represent the upper works; *ef* the line of flotation, and *b* the mast, of the same species with the ship.

It was before proved, in Chap. VIII. of the Appendix, that the weight of the whole ship, including masts and rigging, and all above water, as well as all below water, was equal to the weight of that column of water displaced by the sub-merged part. Now, *g*, the center of gravity of the whole ship, and likewise *i*, the point where the pressure of the water is united, must both be in the vertical plane *bb*; *s* must always be in the center of gravity of the sub-merged part *ebf*, supposed homogeneous; or, which is the same thing, the center of gravity of the column of water displaced by the sub-merged part.

It is evident that if, by bad stowage, the center of gravity of the ship be in *k*, and that of the pressure of the water in *i*, the ship would incline so far to *e*, till the two centers, *k* and *i*, should be in the same vertical *lm* (*Fig. 63.*) the ship would then come to her bearings, and lay fast in the water, but in a very bad condition for sailing.

Now, as the section of the cylinder *elf*, when it is inclined, is similar and equal to the section *ebf*, when upright, it will follow that *i*, the center of pressure of the water, will be in the vertical *lm*; for it will always be in that line which bisects the line of flotation. In this case, the metacenter does not shift, because the section being a circle, all the verticals will pass through the center; tho', in any other form, this point

point would shift higher or lower, according to the inclination of the body: But it may be found by M. *Bouguer's* method, the inclination being given.

It will be proper here to remark, that the center of gravity of the ship will always continue in the same point, even when the ship heels; for if it should happen to be otherwise, by the shifting of the ballast, or any other accident, it would be of very dangerous consequence. If then the center of gravity be in g (*Fig. 62.*) in the line bb , it will continue in that line, when the ship lays over, as in *Fig. 63*; for it will not be in the vertical lm ; but it will endeavour to place itself in that position; and the force of the pressure of the water, exerting itself in the direction of the line lm , both these efforts united will contribute to right the ship; and this will always be the case, if the center of gravity, g , be not placed above the point c towards b ; for, in that case, the weight of the ship, and the pressure of the water, would both contribute to heel the ship.

We may, without having recourse to M. *Bouguer's* geometric nicety, shew how dangerous it would be, to raise g , the center of gravity of the ship, to any considerable height above i , the point where the pressure of the column of water displaced is united, as in *Fig. 64*, if the center of gravity be placed in n , no sooner does the ship begin to heel; never so little, but the force of gravity acting in the direction of the line no , will cause her to heel more, at the same time that the pressure of the fluid, united in the point i , acting in the direction of the line ip , will still raise the body higher; and both these forces will continue to act in concert, till they both come to be in the same vertical bn . It is now very plain, the more we raise the center of gravity towards b , the more we lower the center of pressure of the water towards b , the greater force will these two powers have to overset the ship: It is likewise plain, that if the center of gravity were placed in c , it would contribute nothing either to heel or right the ship. Lastly, the nearer we come to b , the more will it contribute to keep the ship upright; and when the center of gravity is below the center of pressure of the water, these two will act in concert to keep the ship upright.

The center of gravity must not, at any rate, be placed above the point c , which M. *Bouguer* calls the metacenter; but it will be proper here to remark, that C , the center of the arch ebf , (*Fig. 61.*) will serve to limit the center of gravity, even when the body is so light as to sink only to gbb , in an upright, or to ilk , in an inclined position; It is easy to perceive, that if the center of gravity be in the line lm , any
where

where betwixt c and m , the nearer it is placed to b , the greater power will it have to bring the ship upright, by struggling to bring itself into the line lb ; on the contrary, if it be placed betwixt c and m , the nearer it is to m the greater power will it have to overturn the ship.

The center of gravity, then must not be placed above the point c ; but the ship may continue upright, tho' it be placed above n .

The misfortune is, that it is only segments of circles that have their metacenters in their centers, and could they be as easily found in ships it would be a great advantage: It is true, *M. Bouguer* has furnished us with a method to investigate the center of gravity, of a hull in form of a spheroid; but it is not my intention here to follow him in his researches, which he has carried on with all the clearness they are capable of.

As we confine ourselves to what is directly applicable to practice; it may suffice to have shewn what effect the weight of the ship, and the pressure of the water will have upon the stability of the ship, and that, by what we have collected from *M. Bouguer*, we may conclude that the metacenter should be placed a little above the line of flotation; but the center of gravity will be higher or lower according to the form of the bottom, or according to the manner of stowing the hold.

At first sight, it is certain that all the weight above the line of flotation helps to make the ship crank, and of consequence, the lighter the upper works the stiffer the ship, and it is by this method of lightening the upper works, that *M. de Goyon*, captain of one of his majesty's ships; made those ships carry sail which were before thought to be very crank.

The builders may vary the form of a ship, chiefly, in three dimensions, *to wit*, length, breadth, and depth: Let us examine how far enlarging of ships, in any of these particulars, will contribute towards making her carry sail.

If the length only, without altering the other dimensions, be enlarged, the center of gravity and the metacenter will continue the same height, so her stability in respect of inclination to one side will increase in proportion to the weight of the ship; and as the weight generally increases or diminishes in proportion to the length, we may say, that in ships that differ only in length, their stability will be in proportion to their length.

It will be quite otherwise, if we alter the breadth, for, by enlarging we gain, and by diminishing the breadth we lose a great deal of the stability; *M. Bouguer* has proved that the stability increases in proportion to the cubes of the breadths. For, supposing the bottom homogeneous, then, 1st. The increase of weight, and of consequence of stability, will be double the increase of the breadth. 2d. The additional weight will act
with

with so much the greater force, as the length of the lever is increased, or as the metacenter is raised, and the height of that point is augmented in proportion to the square of the breadth; hence, the stability will be increased in proportion to the cube of the breadth: For example, without altering the other dimensions, let the breadths be doubled, we thereby double the weight, which, acting upon the arm of a lever, double the length will be quadruple, so the ship will acquire eight times the stability. We may prove this by an experiment upon two models, the one double the breadth of the other; if a ruler *bl* (*Fig. 65*) be erected perpendicular in the middle of each, and a plumb line fastened thereto, and if likewise an equal weight *n*, be suspended to each lever *bm*, we shall find, by the angle the plumb line makes with the ruler, the stability will be as 8 to 1. We may likewise prove it, by comparing the different angles made by the same weight, or which, perhaps will be more simple, let the inclinations be equal, and, suppose the one model three times the breadth of the other, then we shall find that it will take 27 times more weight to produce the same inclination, or the same weight placed 27 times further from the axis than the other. Hence, in general, the stability will be in proportion to the cubes of the breadths, provided all the other dimensions be equal, so if the breadth be as 1 to 3, the stability will be as 1 to 27, for 27 is the cube of 3.

Experience has proved to the builders what theory has demonstrated to M. *Bouguer*, for without doubt it is for that reason they place the extreme breadth of the midship frame pretty near the line of flotation. It would be very inconvenient to raise the breadth in midships; but by raising the breadth afore and abaft we gain in stiffness. This will appear very plain, if we compare the section that forms a rectangular parallelogram at the load water-line to one that forms a rhomboides, whose acute angles are at the stem and post, which M. *Bouguer* has proved to be four times the stability of the other. Now when, by increasing the breadth, the water lines become less fair, and therefore meets with more resistance in dividing the fluid, it will not from thence follow that will hinder her sailing; on the contrary, as she will thereby carry a great deal more sail, it may assist her going.

We have hitherto considered the bottom as homogeneous, but it is evident, the stiffness of a ship very much depends on stowing the hold, as the center of gravity may thereby be lowered.

If we only increase the depth, without enlarging either the length or breadth, all the stability we can gain will be in the stowage; which is the next thing to be considered.

Supp.

M.

The

The seamen know very well that a ship will not carry a stout sail till loaded so deep that the surface of the water may glance on the extreme breadth in midships, as the line *ef*, (*Fig. 65.*) or a little above *c d*, (*Fig. 66.*) and that they must have a great deal of weight, such as ballast, dinnage, &c. which serves for no other use, but to bring the ship to a proper trim in the water; for if she be too light, as in (*Fig. 66.*) she will lay over till her extreme breadth *g* rests upon the water; hence it follows, that a ship that carries a good sail will heel but little, and ply well to the windward; but if, for want of ballast, the ship be not loaded quite so deep, if she wants but a little, it will be no great disadvantage, for after she once comes to lay over to her breadth she will go no farther, and she will sail very well in that position.

There will be great danger in overloading a ship, for then her guns will not be a proper height out of the water, an article of great importance, and she would meet with more resistance in passing thro' the water; for, admitting her to be loaded to the line *ot*, (*Fig. 65.*) she would displace no more water by heeling to the side *o*, and so the pressure of the water would not contribute with the center of gravity to bring the ship upright.

I shall not presume to determine this point to a nicety, so as to admit of no exception. It may suffice to say in the general, that a ship should be loaded to her extreme breadth; but it is not indifferent what manner of ballast we use, for the quality and stowage of the ballast may very much increase, or diminish, the stability. It is evident then we must have no more ballast than will load her to the extreme breadth; supposing 400 tons, together with provisions, &c. to be sufficient to load a ship to her breadth, we must put no more weight on board, but we may take heavier ballast, by which means the center of gravity will be lowered proportionally to the specifick gravity of the ballast. Hence is deduced the general practice of stowing the heavy goods lowermost, and the light uppermost, whereby the ship will be able to carry the greater sail.

It is not a matter of indifference how goods are stowed in the hold; for, supposing a ship loaded with lead, guns, iron, or and other weighty goods, her hold would not be near full, when loaded to her proper water line; and tho', by placing these goods on the floor, the ship would certainly carry a great sail, yet she would sail very badly, and be in danger of being dismasted by her prodigious rowling and sudden jirks.

The mariners finding by experience how dangerous this would be have in a great measure, found means to prevent it by the dinnage, whereby
the

the heavy goods may be raised, this will make her rowl easy, and go smoothly thro' the water.

What we have said of the stability of shipping has insensibly led us to consider the rowling and pitching; we have already shewn that the rowling may be very much prevented by stowing the hold; the form of the bottom may likewise contribute thereto.

To explain this by an example; let us suppose the section of a ship, perpendicular to the keel, to be exactly round as (*Fig. 63*), it is plain, if this be agitated in the water, it will have nothing to support it, because it displaces no more water when inclined than when upright, and of consequence would rowl prodigiously. But if we put a plank below *b*, suppose to *g*, to run quite fore and aft, it is plain, when the ship is inclined to the right, the plank *g* will displace a column of water to the left, which will retard her motions, and this obstruction will always act contrary to the way the ship heels, and will very much diminish the rowling, but will add very little to her stiffness; for, admitting the ship to heel as in (*Fig. 63.*) the plank *b g* would contribute very little to bring her upright. But the depth of the keel, the rising of the floors, and the dead wood fore and aft, as in (*Fig. 66.*), will answer the same purpose as the plank *b g*.

In regard to the pitching, I am of opinion, the best method that can be taken will be to proportion the capacity of every part to the weight it is to contain, and it will be very dangerous to depart from this rule; we have an instance of it in the *Funo* of 60 guns, which, wanting capacity abaft, was always a very bad failer; and, notwithstanding all proper means were used to remedy this, by moving the iron ballast forward, and the fore-mast guns aft, yet all their endeavours proved unsuccessful, for she sometimes pitched to that degree, that her counter was under water.

It would not be adviseable to build a bad ship on purpose to try experiments; but when we find a ship that has some bad qualities, it will be of singular use to find the proper means to remedy the fault.

In order to comprehend the means to be used to prevent the bad consequences of violent pitchings, let us suppose a ship at rest, and a sea taking her afore; if the bow be well supported, that is to say, if the fore-most frame be pretty full, and her breadth line of the rising of the floors not carried too high, this vessel will infallibly rise with the sea; it is true, when the sea leaves her she will fall again, but it will be easily, because the breadth increases gradually, even above the load water line; and this swelling of the body, being gradual, will hinder the ship from falling with

M 2

sudden.

sudden shocks ; on the contrary, if she be very sharp forward, she will not pitch so much, but she will, in the sea term, bury herself under water forward, so that the foremost guns will be entirely unserviceable in a sea-gate.

We may perceive then, that their are two rocks to be avoided ; though the breadth must be carried above the load-water line, to support the bow that she may rise to the sea, yet it must be divided in parts to prevent violent pitchings.

Let us still consider the ship pitching, or heaving and sending, in a sea-gate ; if the foremost frames have no hollow, that is, if they be strait, from the breadth to the rabbit of the keel or stem, or if the vertical curve resembles a wedge, those ships will fall easy, because the breadth, increasing gradually, the resistance will likewise be gradual ; but, on the contrary, if they are very sharp below, and the frames form a hollow from the rabbit almost quite as high as the breadth, it is plain she will meet with a very sudden shock, as the sea meets with no opposition, till, all of a sudden, it is resisted by the breadth ; so that, in general, it is less dangerous to have a full bow, which will rise to the sea, than a very sharp one which will plunge the ship's fore-castle in.

Hence, the whole art consists in finding the proper mean betwixt these two extremes ; that is, to give the ship such a form as may rise and fall easy into the sea, and likewise not hinder her sailing.

We have now given our readers the substance of what these two eminent mathematicians have said on the theory of Ship-building, and for further particulars, beg leave to refer them to the originals ; they will then be able to judge how far they have succeeded in determining the necessary *data* ; one thing may be remarked, that they at last refer us to experience, but experience seems not to agree with M. *Bouguer's* principle, on which he says the velocity depends : For he asserts, that if the midship frame be carried before the middle of the ship, it will obstruct the velocity ; because the bow will thereby become fuller ; however he places it at one twelfth of the length before the middle, to give the helm more purchase.

I shall now give our readers an account of some experiments taken by one of our own countrymen, whose abilities are unexceptionable. He, by long experience, and unwearied application, has made several useful discoveries, which baffled the deepest researches of the most eminent mathematicians ; his experiments prove beyond dispute, that we shall gain in point of velocity, in carrying the midship frame before the middle, perhaps
at

at two thirds of the length from the after end. I shall not take upon me to assign the reason of this, but there is no disputing against matters of fact, perhaps it may be owing to what I said on that head, when treating of towing a mast, butt end foremost, or it may be on account of the center of gravity, which will thereby be further forward; it must be allowed this last circumstance will give the helm more purchase, tho' it cannot be discovered by his experiments, the whole design of these experiments being to determine the form of that body which will go thro' the water with the greatest velocity, and to ascertain the most advantageous situation of the midship frame, and that this must be nearer the fore part than the after part, he has demonstrated in such a clear, elegant, and familiar manner, that I should only discover my own weakness, in presuming to say any more on that head; so I shall give it in his own words.

Of the Friction, or lateral Pressure of Water.

THE cylinders made use of in the following experiments were solids of seasoned oak, 36 inches long, by four inches and a half diameter; the sides were strait, and turned exactly round.

A, in *Fig. 74.* is the standard to make the comparison from; when the pieces 1, 2, 3, 4, 5, are screwed together, they make the cylinder B equal to A, these are drawn thro' the water with the end 5 foremost; until (by encreasing or lessening the weight a little at the roller or pulley) the velocities agree.

After which take out 2, and put together 1, 3, 4, and 5, which makes the figure C to be one fourth part shorter than A, at which time it gains the velocity of one eighth.

Then take out 3, and put 1, 4, 5, together, and it makes the cylinder D; which being drawn against A, as before, it makes the velocity one fourth part more.

After which, if we join 1, 2, 3, 4, and 6, together, it makes the cylinder E, with no more difference from A, only that there is a direct flat superficies in lieu of a convex; this drawn against A, loses in velocity one sixth part.

Take off 6 and join 7; it makes the figure F, a concave, and, when drawn as before, it loses one fourth part of the velocity.

When the flat superficies is drawn hindermost, it loses one twenty-fourth part. When the concave is drawn hindermost, it loses the same one twenty-fourth part.

From

From such experiments, we may gain a proportion for lateral pressure, or friction; we also see the great difference between a convex and a flat superficies to separate the water; and the difference between a concave end to separate the water and a flat superficies; also between a concave and a convex end; and also, that there is a sensible difference as to its separating the water, by being foremost, tho' not so by the closing in of the water by being hindermost.

These things may be of service in theory, and seem capable of being improved by further experiments.

NOTES relating to EXPERIMENTS.

Method for knowing the lines of least resistance. Intended for the purpose of forming the bodies of ships; also, relating to an attempt for finding the proportion for the friction or lateral pressure of water.

Provide a cistern for the water as represented in the plate (Fig. 75), not less than 30 feet long, and divide it in halves by a partition length ways, that the motion of the water in one part may not disturb that in the other; observe, as the least blowing of the wind disturbs the surface, it is best to be under cover, namely, in a shed or warehouse.

Observe the pulls, represented on the plate, be made very exact, the lines may be silk or *Indian grass*.

There must be also a line strained very tight over the middle of each water, and wires fixed upright in the end of each block or solid; which by the ends, turning back over the line, keeps the block or solid direct in its course.

At each end of the block is fitted a small staple, by which the lines fasten with a hook to draw the block; there must be time given between each drawing for the water to become still.

The blocks must be as near as possible equal in weight, and swim truly level with the surface of the water; if they do not, it must be remedied by cutting out a small piece, or by making a groove in the solid, and so trim the block by putting in small shot: The whole will require much care and exactness.

The figures represent solids, whose lengths are 2 feet 3 inches, and diameters something less than one third of their lengths; these are made perfectly round, one end of these solids is of one shape, the other ends vary as the figures represent.

The

The quantities and weights are made equal and drawn thro' the water, with equal power, that is, first make the standard solids agree in velocity, then fix equal weights to the lines that pass over the rollers.

Whoever repeats these, or proceeds in making other experiments will do well to observe, what weight nearly he chooses to use; for, if the power is very small, a little obstacle may impede the motion of the solids too much. If the weight is great, the velocity will be too much for the observer to decide with exactness the difference of velocity between the two moving solids.

P O S I T I O N.

These blocks being perfectly round, and as the water presses on bodies in all directions, therefore, these blocks are truly represented by single lines in the figure A, B, C, D, in (*Fig. 76.*) and without having other lines of different curves intermixt with them; so that which soever of these solids shall have the greatest velocity, has so far the lines of least resistance.

E X P E R I M E N T.

There were two blocks or solids represented by figure A, of equal weight, size, and velocity. This velocity was made equal by altering a little the weight that passes over the brass roller; one of these solids is made a standard to try the other, otherwise we could not have known so perfectly which end foremost, of A, would have the greatest velocity.

Reverse the ends.

A drawn against A equal velocity.	$\left. \begin{array}{l} \text{H against A loses about one 27th.} \\ \text{G against A loses about one 16th.} \\ \text{F against A gains about one 14th.} \\ \text{E against A loses about one 9th.} \end{array} \right\}$
B against A gains in velocity about one 16th.	
C against A loses in velocity about one 70th.	
D against A gains in velocity about one 9th.	

Observe, that if the brass rollers are not exact, they will affect the motion of the solids; so that it is proper to change each solid, together with its weight, over each roller, for the same reason we change the weights to try scales. The roller which upon careful trial appears to increase the effect of the weight may be lessened in the circumference, or the other increased in the circumference.

D hath the greatest velocity, I say it is because the breadth declines nearer the head than in the others, which eases the lateral pressure sooner than in the others. The extreme breadth of the figure

figure B, is nearer the end, which breaks open the water sooner, but then the breadth is continued further aft, by a strait side, so that the friction is not eased by the declining of the sides so soon as in D, and therefore the difference in velocity is accounted for as before.

Experiment with the Solids I, K, L. (Fig. 77.)

I, and K, are two distinct blocks, the extreme breadth of each is in the middle; they are equal in quantity, equal in length, and equal in weight, but not equal in breadth. The block K is narrower in the middle and fuller towards the ends: The block I is broader at the middle, and narrower towards the ends; they are drawn, and found that K hath more velocity than I, by one forty-sixth part.

L is the same length, same breadth, same quantity as I; the extreme breadth of this is removed from the middle to one third of the length from one end, by which means one end is fuller, and the other just so much the sharper, and the floor shorter; this drawn, the full end foremost, against I, gains in velocity one ninth part, and when the sharp end is foremost, it loses one ninth part.

Doth not this shew, that if a ship was built with the lines that form the body similar to the solid whose breadth is in the middle, and if another was built with the lines that form the body similar to the solid whose breadth is one third from the stern, the latter would lose of the former one ninth part of the velocity?

If another ship was built, whose lines that form the body were similar to the solid whose breadth lay at one third from the head, it would outfail the ship whose breadth lay in the middle one ninth part. Also, that the ship whose breadth lay at one third from the head, would outfail the ship whose breadth lay at two thirds distance from the head, two ninth parts of the distance run.

The absolute and relative force of a current of water, against the forepart of a ship, may be computed from the sines of the angles of incidence taken in many parts, as is described by M. Dubamel, or some other way equal thereto, as far aft as the midship frame; and as the midship, or the widest frame may be placed in the middle, or further aft or further forward, and the quantity of the bulk remain the same in the whole; so by moving the midship frame further aft, the lines that form the fore end of the ship thereby runs nearer a parallel to the keel, and consequently have the less absolute resistance to the current of water; but this accounts but for one part only, that is the resistance of the current

rest from the stem to the middle of the ship. Yet there is a friction, if I may so call it, from the lateral pressure of the water against the sides and bottom of the ship that must be considered also, which I will endeavour to explain in the manner following. Water, according to its depth, is by its own weight compressed together, against the ends, sides, and bottom, in all directions; if the body placed therein be not specifically heavier, the water will bear it up, and, in proportion, as the body is lighter, the more it will float out of the water; this is familiarly known, but the applying this to the present purpose may bear stating in this manner.

Water, or any liquid, placed in a box, or vessel of any figure, presses against all the sides with a force equal to its depth, and, at the same time, the whole weight on the bottom. On the contrary, when a vessel is placed in water, the water presses the sides and ends inwards, and upwards, under the bottom, with a force to bear up the vessel, ship, or any other figure whatever, that is not specifically heavier than the water.

The moving this body, as it is thus circumstanced, with the water pressing against it on all directions, must put all the parts of the water that are next, or near it, in a ruffle and sort of confusion; the particles at the fore-end of the ship, near the bottom plank, appear to be constantly removed by fresh particles of the current pressing in, and impelling against them, and so one after another; but when we come to a more strait part of the ship's sides, and the declining part of the ship's bottom, the particles next the plank are not so soon displaced; this appears, from observing the grass that grows on the sides of the ship; it shall be seen to grow right out, and wave backwards and forwards, from the sides of the ship, as if the water had no motion, when at the same time, the ship may be sailing three four or five knots an hour, or more: This is, in part the case when the ship's bottom is clean, but much more so when the bottom is foul. This atmosphere, or carrying part of the water along with the ship, is what I have here called friction, and is to be considered, and must be taken into the account of the resistance. In order to form some conception thereof, the solids, represented by the figures, were contrived, being turned exactly round, and the water pressing in all directions, they are by me esteemed as single lines.

By these experiments, it appears, that by moving the middle frame from the middle, nearer one end; that end unto which the widest frame is nearest, gives the greatest velocity, when turned foremost, and so contrariwise it is reverse.

Supp.

N

Now

Now it is plain, that by so doing, the entrance of the ship doth make a more sudden, or is of more absolute force against the current of the water, than when in the middle of the ship, or solid, on which the experiment is tried. To account for this, I am satisfied with conceiving that by moving the midship frame nearer the fore-end of the ship than in common is done, the body thereby declines so much sooner, and takes off part of the friction caused by the lateral pressure, which appears to be of more service to the velocity, than what is lost by making the fore part of the ship somewhat fuller.

To insist that the difference in velocity of these experiments, as set down to that account, is exactly neither more nor less, than what is there mentioned, may not be strictly or scrupulously true, but that it is near the truth is demonstration; and it hath been long ago shewn by Sir *Isaac Newton*, that a blunt headed figure, impelled in the direction of its axis, was the shape of least resistance in a fluid; but the properest proportion between the length and breadth is not deduced.

In the next place it resembles nature, in the form of the fast swimming fishes, and hath been experienced with success; from all which it is become to me a rule, or pattern, that, so far as other considerations will admit, the lines that form the bodies of ships should be similar to the pattern that had the greatest velocity.

Suppose a cruising ship had all the perfections in her dimensions, and every other part, and the midship or broad-side frame placed near the middle of the ship, and built sharp at the ends; consider the weight of the fore-mast, rigging, and sails, belonging to her; the anchors at the bows, which, with the pressure of the wind into the sails, all unsupported but from the body farther aft, and united to press down into the hollow of every sea; I say, for want of more body further forward, such a ship must plunge deep, and hinder the velocity; this is not the case of the hinder part of the ship. Another consideration is, the side resistance of the bottom of the ship must not be equally forward to that abaft, for, if it was, the ship must be trimmed greatly by the stern, or her rudder would not command her, to bear up in a gale of wind. When a ship is preft with sail, the water is forced up at the bow, a little above a level, and the ship is pressed a little down, which amounts to the same, with respect to her helm, as if the ship was trimmed by the head. Then ships that carry their tiller near the middle in light winds, require it more a weather, when it blows. Suppose, by moving the midship frame a little farther forward than M. *Dubamel* proposes, and is commonly done,
if

if it did not add to the velocity, by so doing, provided it retard not the motion, it is of service for the reasons mentioned.—So far these Experiments.

We may now venture to assert, that by carrying the midship frame forward, as in the preceding experiments, we shall gain, not only in point of velocity, but likewise, according to M. *Bouguer's* own principle, in point of steerage, which will be a double advantage.

As these experiments were made in still water, it may be presumed, when a ship is to encounter a great head sea, there will be at least as much, if not more occasion for a full bow.

The Method of bevelling the Cant Timbers by the Diagonal Ribbands, and likewise the Fashion Piece of a Square-Tuck, by Water Lines.

* *To bevel the Cant Timbers by Ribbands.*

THE angle Fob , (Plate VII. in the foregoing treatise) will be the angle which the fashion piece will make with the third ribband : For o being the point where the plane of the fashion piece intersects the third ribband ; a line drawn from o to F , will be the line in which the plane of the timber intersects the plane of the ribband : But then, as these planes are not perpendicular to one another, the angle Fob will not be the true bevelling, unless the bevel be so applied that the tongue may be in the direction of the ribband, and then the stock cannot lay flat upon the side of the timber :: For which reason this method will not do for practice ; for the surest way to take any bevelling, is when both the stock and the tongue of the bevel are square to the timber.

In order then to find the true bevelling upon a square, the direction in which the ribband intersects the timber must be given, as well as the angle Fob ; and likewise the breadth of the timber : Now if these three be given, the angle upon the square may with certainty be found by the follow method.

Let the distance betwixt the parallel lines AB and EF be the breadth of the timber ; Ba the direction of the ribband ; and ab what the bevelling is without a square. (See the Fig. under the Scale, Plate VII.)

Now, that we may the easier conceive how this bevelling may be found, let us suppose the timber to be quite strait, suppose the partition of the chest, Page 124 ; and first trimmed square. Then, because ab is what it is without a square, it is plain there must be so much lined off the aft side of the timber ; the line aB will be the breadth of the outside of the timber, in that direction before the wood is taken off ; and if BD be made equal to Ba , and Dd equal to ab , and the angle at D a right one ; then it is plain the angle ABd , equal to the angle Fob , will be the bevelling, if the tongue of the bevel can be kept in the direction of the line Ba : But when the stock of the bevel is laid flat on the side of

* These directions are again inserted in the Supplement for the benefit of the Purchasers of the first Edition.

the timber, the tongue will naturally be perpendicular to the plane of the timber, which will be in the line BF ; and if Ff be made equal and parallel to Dd ; then will the angle ABf , be the true bevelling upon a square.

DEMONSTRATION. (Plate VII.)

In the right angled triangle aFB , BF the breadth of the timber is given, and aB the common section of the plane of the ribband, with the plane of the timber; again in the right angled triangle baB or BDd , its equal, we have aB or BD the breadth of the timber in the direction of the ribband, when the timber is yet square, and ba , or Dd , what the bevelling is without a square, so the angle ABD will be the bevelling.

But if BF were the common section of the ribband, and timber, then the line of direction would be square to the timber, which does not alter what the bevelling is without a square, viz. the line aB or Dd .

In the right angled triangle FBf , Ff , and FB are given, hence we have the angle ABf , the bevelling on a square; but it is plain the ribband will be higher on the aft than on the fore side, when in the after body, and the contrary when in the fore body; therefore the height of the ribband must be transferred from the contra to the moulding side, which must be the firmark when the bevel is square to the timber; so the first thing to be done, is to find the height of the ribband, on the contra side, for its height on the moulding side is given before the timber can be formed.

Before we give direction how to find this, it will be proper to observe, first, that tho' the planes of the square timbers intersect the planes of the ribbands in the diagonals, in the body plane, yet the cant-timbers do not, for the plane of the 4th ribband cuts the plane of the fashion piece, in the line rF , and not in the line rs . Secondly, we must remark, that the breadth of the timber must be determined, which, suppose Fe in the floor plane, so shall rB represent the foreside of the fashion piece, on the floor plane, it being parallel to FP , which represents the aft side: Let Fe be square to the point F , so the fore side of the plane of the fashion piece must be broader than the aft side, by the length of the line Be , that being what its bevelling to the sheer plane is without a square; this being premised, we may find the height of the third ribband, on the contra side of the fashion piece, and from thence find the bevelling of the cant timber by the following method:.

1st.

1*st*. Take $B e$, that is, what the fore side of the plane of the fashion piece is without a square; set this off on the perpendicular $r d$, in the body plane, and draw the line $d d$ parallel to $K O$.

Note. The line $d d$ will be in the fore body for the after cant timbers, and in the after body for the fore cant timbers.

2*d*. Produce the common sections of the planes of the ribbands, on the aft side of the fashion piece, to cut the line $d d$, as $F r$ in the plate meets the line $d d$ in e .

3*d*. From the point d draw a line parallel to $r F$, which will be the common section of the plane of the ribband and the plane of the fore side of the fashion piece; use the same operations for finding the other ribbands, as you see in the plate, and call them new diagonals.

4*th*. Find points in these new diagonals thro' which the curve of another cant timber would pass, this will be the fore side of the fashion piece, observing that the lines taken from the floor plane must be set off from the line $d d$, and not from the line $K O$; the distance of these points from the curve of the aft side of the fashion piece will be what the bevellings is, within or without the square. In applying the bevel, the stock must be laid on the new diagonals, but when this is not square to the timber, take the nearest distance to the curve of the moulded side of the timber from the fore said points, and there place the firmark, so the stock and tongue will be square to the timber, as in the first ribband, and from these points make an exact bevelling board, as in the plate; the like process may be used for the fore body.

The difference of the height of the ribbands on the moulding, and contra side, may be had by projecting the planes of the diagonal ribbands on the sheer plane. The forms and bevellings of all the other cant timbers may be had by the same method, but every timber will require another line, for the line $d d$ will fall betwixt that and the line $K O$, till at last it coincides with it, that is, when the timber has no cant, and the new diagonals will be approaching to those that represent the planes of the square timbers in the body plane.

The cant timbers may likewise be bevelled by water lines; their planes are represented by level lines in the body plane, which, in some cases, will be very oblique to the curve of the timbers, but this may be reduced to a square, and the bevellings found as before directed: See that of the first transom in the plate.

To bevel the fashion piece of a square tuck by water lines.

The fashion piece of a square tuck may bevelled by water lines, in the same manner the cant timbers are by ribbands, for as it both rakes and
cants,

cants, the planes of the water lines will intersect it higher on the aft than on the fore side; and, before we have their heights on the fore side, the breadth of the timber must be determined, which suppose bn (*Fig. 71.*); but this is not all, for, as it cants, the breadth in the direction of the water line, will be more than the true breadth: In order to find the true breadth, form the aft side of the fashion piece, as directed in page 140; but, as we intend here to allow for the thickness of the plank, we shall alter both the rake and cant.

Let $t5$ (*Fig. 69.*) be the aft side of the rabbit on the out side of the post; WM the common section of the plane of the fashion piece, and sheer plane; but before this last line can be determined, draw the several water lines 1, 2, 3, 4, and 5, parallel to the keel, which may represent so many transoms; let all these water lines be formed and ended at the aft side of the rabbit, as in *Fig. 70*, where the round aft of the transoms is described, and limits the curves of the water lines. Now the line WM must rake so as to leave room for half the thickness of the post at the tuck; in order to which, produce Wg to r , make rg half the thickness of the post, thro' r draw a line parallel to gM , to intersect gG in b ; with the radius rb from x , the point of the tuck as center, describe an arch, and draw the line WM just to touch the back of that arch.

The lines parallel to gG must likewise be so drawn as to cut off no part of the transoms in (*Fig. 70.*) the lines gG , $a4$, $s3$, are abaft the ends of the transoms, so all that wood must be taken off after the fashion piece is bevelled.

Having thus drawn the line WM , first assume any point k , at pleasure; in the line WM , *Fig. 69*, let fall the perpendicular ky , and draw yf parallel to gG , to intersect a perpendicular drawn from the point M in f , *Fig. 70*.

2d. From M draw the line $M1$ square to yf , and then the line yn square to WM .

3d. Make Mn , *Fig. 71*, (equal to $M1$, *Fig. 70.*) the base of the right angled triangle $k n M$, of which Mk is the perpendicular equal to ky ; so the angle $k n M$ will be the bevelling to the horizontal plane; and to find its bevelling to the sheer plane.

1st. Make Mz , *Fig. 71*, (equal to ny , *Fig. 70.*) the base of the right angled triangle $f z M$, *Fig. 71*, of which, fM the perpendicular, is equal to fM , *Fig. 70*; so the angle $f z M$ will be the bevelling to the sheer, as demonstrated in page 126.

Having thus found the bevellings, draw the line ab , *Fig. 71*, parallel to zn ; let az , equal nb , be the scantling of the timber, then nx will be the

the breadth of timber on the horizontal, and zc its breadth on the sheer plane, and ac what it is within a square.

Now, as the lines $gG, a4, s3, b2, y1$, represent the aft side of the fashion piece on the horizontal plane, *Fig. 70*, we may draw the dotted lines parallel to them to represent the fore side as in the plate; making nx , *Fig. 71*, the square distance betwixt them, and their correspondings on the aft side, and by these dotted lines form the fore side of the fashion piece in the same manner the aft side was formed; but the water lines on the fore side of the plane of the fashion piece must first be drawn, in *Fig. 69*. Thus,

1st. Draw the lines eb and cd parallel to WM , (*Fig. 69*.) making the distance betwixt WM and eb equal to ac , (*Fig. 71*.) and the distance betwixt WM and cd equal to zc . (*Fig. 71*.)

2d. Draw a line parallel to WF , through the point where the line cd intersects the fifth water line, *Fig. 69*; draw a line parallel to aA , through the point where the fourth water-line intersects the line cd . Do the same by all the water-lines.

We may now project the fore-side of the fashion-piece by the new water-lines, observing that the distances must be set off from the line eb , and not from the line WM ; or find the points through which the curve should pass on these new water-lines, and the nearest distance betwixt these points and the curve of the aft side, is what the bevelling is without a square, when both stock and tongue are square to the timber; and, when the water-lines are not square to the timber, reduce the bevelling to a square one, and place the firmarks on the moulding edge, as you see in the plate, and from thence transfer the bevellings to a board, the exact breadth of the timber.

After the timber is trimmed and bevelled from the aft side, there will be a spiling, ed , (*Fig. 70*.) to be set off forward from the line Gg produced; and a spiling, co , from $a4$ produced; lastly, a spiling, lm , from $s3$ produced; and as the aft side of the fashion-piece winds, there must likewise be spilings set off for the inside, as in *Fig. 69*.

Let $11, 12, 13, 14$, *Fig. 69*, be the inside of the fashion-piece; make $g, 11$, *Fig. 70*, equal to $W, 11$, *Fig. 69*; $a, 12$, *Fig. 70*, equal to $a, 12$, *Fig. 69*, &c. So $11, 12, 13, 14$, will be the spilings, and wear off at the point 1 ; *Fig. 70*.

There will be no occasion to side the moulding side of the fashion-piece quite strait; it may be sided so, that, when the mould is slightly fastened to it, the head of the fashion-piece may round from the mould nearly the whole quantity of the spiling, and then it may be bevelled from the mould, and afterwards the proper spilings set off.

Th

The timber being thus trimmed, the planks will come to the aft side of the fashion-piece, which will make the ends apt to start off with the caulking; to prevent which the thickness of the plank must be set off without the moulding edge of the fashion-piece, as in the plate; and, when the fashion-piece is bevelled to this mould, we shall have the whole thickness of the plank, without the moulding edge both of the aft and fore sides; so the planks may be rabbitted into the fashion-piece, leaving substance enough on the aft side to cover the ends of the planks. The planes of the timbers, in some cases, cut the plank very obliquely, which will occasion the plank to be thicker in that direction than really it is; therefore the thickness of the plank, in the direction of the plane of the timber, at each water-line, must be determined before the mould can be made. This will be a very difficult task; however, we shall endeavour to perform it in the following manner.

1st. Draw a line square to the second water-line, at the point 2, where the plane of the fashion-piece intersects it on the floor plane, *Fig. 70*; and produce this line, from the middle line, to intersect all the other water-lines, which must be produced for that purpose; so the square line, in *Fig. 70*, will be 2, 2, v.

2d. Form a cant timber in the direction, or cant of that line, as in *Fig. 68*.

3d. Set off the real thickness of the plank square from this timber, to intersect the corresponding water-line in the point *r*; so *rs* will be the thickness of the plank on the plane of the water-line.

4th. Set off *rs* parallel to the second water-line, *Fig. 70*; to avoid confusion this was done by a pencil, and we have only the point *t* in the plate, where the plane of the fashion-piece intersects it.

5th. Produce *bz*, *Fig. 70*, to intersect the curve in *t*; so *tz* will be the thickness of the plank in the direction of that line.

6th. Produce the line *bH*, *Fig. 69*, to *q*, making *bq*, *Fig. 69*, equal to *bt*, *Fig. 70*; so *q* will be one point of the curve.

Though this method may be too tedious for practice, yet, as it seems to bear a mathematical demonstration, we have adventured to insert it; far from imagining that there are not other methods better adapted for that purpose; for, without some such contrivance, a ship could not be built exactly of the same dimensions with another already built, having only the dimensions of this last, by taking them off when in a dock, which must be from the outside of the plank; whereas, when they form the timbers, the dimensions must be taken from the inside of the plank.

Supp.

O

On

On the Mastiug of S H I P S.

AS M. *Bouguer* has given us the general proportions for the length and diameter of masts and yards used in *France*, it may be expected we should give the proportions used in *England*.

It must be owned, the art of mastiug ships is quite as imperfect as that of forming the bodies, for they bear no manner of proportion to any of the other dimensions of the ships, and seem to be wholly regulated by the judgment and experience of the commanders. This will appear very plain by examining the dimensions of the masts and yards of the following ships, and comparing them with the breadths and lengths of those ships, and yet their commanders were all allowed to be expert seamen.

Dimensions of Masts for EAST-INDIA Ships.

	Length. Feet.	Diameter. Inches.		Length. Feet.	Diameter. Inches.
MAIN-MAST	80	$24\frac{1}{2}$	MAIN-YARD	66	$16\frac{1}{2}$
Top-mast	50	15	Do.	52	$12\frac{1}{2}$
Top-gallant-mast	28	8	Do.	36	6
FORE-MAST	72	24	Do.	60	15
Top-mast	48	15	Do.	48	12
Top-gallant-mast	25	$7\frac{1}{2}$	Do.	34	$5\frac{1}{2}$
MIZEN-MAST	70	17	Do.	61	$12\frac{1}{2}$
Top-mast	36	10	Do.	36	$7\frac{1}{2}$
Bowsprit	50	25	Do.	50	12
Jyb-boom	36	11	Crossjack	50	$11\frac{1}{2}$

Dimensions of Capt. KENNEDY's Masts and Yards, of about 182 Tuns.

	Length. Feet.	Diam. Inch.		Length. Feet.
MAIN-MAST	62	$16\frac{1}{2}$	YARD	44
Top-mast	33	10	Do.	32
Top-gallant-mast	18	$5\frac{1}{2}$	Do.	24
FORE-MAST	56	$16\frac{1}{2}$	Do.	39
Top mast	30	$9\frac{1}{2}$	Do.	30
Top-gallant-mast	16	5	Do.	22
MIZEN-MAST	53	11	Do.	40
Top-mast	28	$6\frac{1}{2}$	Do.	24
Bowsprit	36	$16\frac{1}{2}$	Crossjack and spritsail	32 feet long;
Extreme breadth	23		Spritsail topfail-yard	24
Length on the lower deck from the aft side of the stem to the fore side of the stern-post				f. in. 81 8

Di-

*Dimensions of Captain ALLEN's
Masts and Yards, about 176
Tuns.*

	<i>Masts. Yards.</i>		
	<i>Length.</i>	<i>Diam.</i>	<i>Len.</i>
	<i>Feet.</i>	<i>Inches.</i>	<i>Feet.</i>
MAIN-MAST	63	16 $\frac{1}{2}$	44
Do. top	33	10 $\frac{1}{2}$	33
Do. top-gallant			25
FORE-MAST	58	16	39
Do. top	31	10 $\frac{1}{2}$	33
Do. top-gall.			23
MIZEN-MAST	53	11 $\frac{1}{2}$ h.miz.	
Do. top			25
Bowspit	37	16	31
		Crossjack	32
Breadth	23 f. 2 in.		
Length low. deck	78 feet, 11 $\frac{1}{2}$ in.		

Capt. LYONS, about 167 Tuns.

	<i>Masts. Yards.</i>		
	<i>Length.</i>	<i>Diam.</i>	<i>Len.</i>
	<i>Feet.</i>	<i>In. h.</i>	<i>Feet.</i>
MAIN-MAST	60	16 $\frac{1}{2}$	42
Do. top	33	10	32
Do. top gall.	18	5 $\frac{1}{2}$	24
FORE-MAST	54	16	37
Do. top	30	9 $\frac{1}{2}$	30
Do. top-gall.	16	5	22
MIZEN-MAST	52	11	40
Do. top	28	6 $\frac{1}{2}$	24
Bowspit	36	16 $\frac{1}{2}$	32
		Crossjack	32
Breadth	22 feet, 6 inches.		
Length low. deck	79 feet, 1 inch.		

Capt. BOWMAN, about 162 Tuns.

	<i>Masts. Yards.</i>		
	<i>Length.</i>	<i>Diam.</i>	<i>Len.</i>
	<i>Feet.</i>	<i>Inches.</i>	<i>Feet.</i>
MAIN-MAST	60	16	41
Do. top	32	10	31
Do. top-gall.	17	5	24
FORE-MAST	54	15 $\frac{1}{2}$	36
Do. top	28 $\frac{1}{2}$	9 $\frac{1}{2}$	28
Do. top-gall.	15	4 $\frac{1}{2}$	22
MIZEN-MAST	50	11	20
Do. top	25	6	25
Bowspit	34 $\frac{1}{2}$	16 $\frac{1}{2}$	30
		Crossjack	30
Extreme breadth	22 feet, 6 inches		
Length lower deck	76 feet, 6 inches		

Capt. DERRY's, about 150 Tuns.

	<i>Masts. Yards.</i>		
	<i>Length.</i>	<i>Diam.</i>	<i>Len.</i>
	<i>Feet.</i>	<i>Inches.</i>	<i>Feet.</i>
MAIN-MAST	58	16	40
Do. top	31	9 $\frac{1}{2}$	30
Do. top-gall.	18	5 $\frac{1}{2}$	23
FORE-MAST	52	15 $\frac{1}{2}$	36
Do. top	29	9 $\frac{1}{2}$	28
Do. top-gall.	15	5 $\frac{1}{2}$	21
MIZEN-MAST	49	11	37
Do. top	27	7	23
Bowspit	35	16	30
Gibb boom,		7	27
Extreme breadth	22 feet.		
Length l. deck	74 feet, 4 inches.		

Capt.

Capt. HILL, 130 Tuns.

	<i>Masts.</i>			<i>Yards.</i>		
	Lengths.	Heads.	Diam.	Len.		
	Feet.	f.	in.	Inch.	Feet.	
MAIN-MAST	55	7	6	14 $\frac{1}{2}$	39	
Do. top	29	3	3	9	30	
Do. top-gall.	18	3	0	4 $\frac{1}{2}$	23	
FORE-MAST	50	7	0	13 $\frac{1}{2}$	35	
Do. top	27	3	0	8 $\frac{1}{2}$	29	
Do. top-gal.	16	2	0	4 $\frac{1}{2}$	21	
MIZEN-MAST	46	5	0	10	22	
Do. top	21	3	0	6	24	
Bowsprit	35			14 $\frac{1}{2}$	29	
Extreme breadth		21	f.	2 $\frac{1}{2}$ in.		
Length lower deck		67		4		

*Capt. HOULDERSON, Billander,
about 160 Tuns.*

	<i>Masts.</i>			<i>Yards.</i>		
	Lengths.	Diam.	Len.			
	Feet.	Inch.	Feet.			
MAIN-MAST	68	16 $\frac{1}{2}$	40			
Do. top	68	10	29			
FORE-MAST	54	15	38			
Do. top	30	9	29			
Do. top-gallant	18	5	23			
Bowsprit	36	15	26			
Gibb boom						
Breadth	21	feet.				
Lower deck length	71	f.	4 in.			

Capt. — —, 131 Tuns.

	<i>Masts.</i>			<i>Yards.</i>		
	Len.	Diam.	Len.			
	Feet.	Inches.	Feet.			
MAIN-MAST	57	16	40			
Do. top	30	9 $\frac{1}{2}$	30			
Do. top-gallant	18	5	23			
FORE-MAST	52	15 $\frac{1}{2}$	35			
Do. top	28	9 $\frac{1}{2}$	28			
Do. top-gallant	15	4 $\frac{1}{2}$	21			
MIZEN-MAST	50	10 $\frac{1}{2}$	22			
Do. top	26	6 $\frac{1}{2}$	23			
Bowsprit	34	16	30			
Crossjack			30			
Breadth	21	feet,	2 inches.			
Lower deck length	73	f.	3 in.			

Capt. ROBIN'S, Snow, 130 Tuns.

	<i>Masts.</i>			<i>Yards.</i>		
	Len.	Diam.	Len.			
	Feet.	Inches.	Feet.			
MAIN-MAST	56	15	40			
Do. top	30	9	30			
Do. top-gallant	17		24			
FORE-MAST	50	14 $\frac{1}{2}$	36			
Do. top	28	9	28			
Do. top-gallant	15		22			
Bowsprit	35	15	30			
Breadth	21	feet.				
Lower deck len.	71	feet,	4 inches.			

N. B. The three lower masts were shortened two feet each, and the yards ten inches at each end.

Capt.

Capt. SMITH's Sloop, 100 Tuns.			Capt. GILBEE's Sloop, 83 Tuns.			Capt. NICKALL's Sloop, 52 Tuns.		
	Length	Diam.		Length	Diam.		Length	Diam.
	Feet.	In.		Feet.	In.		Feet.	In.
Mast	80	19	Mast	73	17	Mast	65	15
Bowprit	44	15	Bowprit	42	14	Top-mast	14	
Boom	52	12½	Boom		50	Top-gallant mast	21	5
Gaff	28		Spread-yard	37		Bowprit	40	11
Spread-yard	40		Top-fail-yard	26		Boom	44	
Topfail-yard	33		Crossjack	33		Gaff	24	
Crossjack	36		Top-gallant-mast	13		Spread-yard	34	
Top-gallant-mast	19		Do. yard	22		Topfail, Do.	27	
Do. yard	28		Gibb boom	26		Top-gallant, Do.	26	
Gibb boom	30		Breadth	18 f. 9 in		Crossjack, Do.	30	
Breadth	20		Length	57 f. 2 in		Breadth	16	
Length	61							

Proportions for Masts and Yards in the Royal Navy.

THE masts are proportioned to the extreme breadth of the ship from out to out, and the yards to the length of the gun deck, and as this treatise is chiefly designed for the ship-wrights of his Majesty's dock yards, we shall here give the general proportions of masts and yards, for the benefit of such of them as may be employed at sea.

As to the form of masts and yards, the general method is to quarter the masts from the partners to the hounds, and the yards from the slings to the yard arms; so that both yard arms are exactly the same, except the mizen yard. The diameters at the quarters are in proportion to that at the partners or slings; whether this curve will be an arch of a circle or of an ellipse, or only a fair curve, we shall not at present examine, only give our readers the proportions; but as the beams are allowed to be arches of circles, we shall here shew a ready way of making a beam mould.

Let A B, *Fig. 73*, be the length of the beam, C D the round in the middle, so it is only describing a circle thro' the three points A D B; but as the circle in some cases will be so large that we cannot come at the center we may use the following method.

1st. Draw the lines A D and D B.

2^d. From

2d. From the center D , and with the radius DC , describe a circle; make the arch ae equal to the arch Ca , and the arch bf equal to the arch Cb , so the arches ae , and bf , will be equal, and of consequence, the angles ADC , ADe , BDC , BDf , will all be equal.

3d. Divide the lines DC , De , and Df into as many equal parts as you propose to find points in the curve; it is indifferent whether these parts be equal or unequal; only observing to begin the divisions from the point D , and that the divisions of the lines De , and Df , be the same distance from the point D that their corresponding divisions in the line DC are from the same point.

4th. Draw the line Bx to the first division of the line Df , and a line from A , thro' z (the first division of the line DC), to intersect the line Bx in g , which will be one point in the curve.

In like manner the other points are found, by drawing lines from B to the several divisions of the line Df , and lines from A thro' the corresponding divisions of the line DC , to intersect those drawn from B , which will all be in the circumference of the circle. In the figure we have only drawn the lines Bx , and Ag ; but, in practice, we may take two chalk lines and fasten one at A and the other at B , and stretching the one thro' the points in the line DC , and the other thro' the corresponding points in the lines Df , and De , the intersections of the chalk lines will give the several points in the circumference.

DEMONSTRATION.

The angle at the circumference of a circle is measured by half the opposite arch, as demonstrated in page 28. Hence all angles at the circumference of a circle that stand on the same chord are equal, and of consequence, if there be never so many equal angles standing on the same chord, they will be all in the circumference of a circle; or, which is the same thing, a curve drawn thro' the several angular points will be an arch of a circle.

The triangles BDx , and ADz are equal, for the sides AD , and DB are equal, the sides Dx , and Dz are likewise equal, and the angle BDx included by the sides BD and Dx , equal to the angle ADz , included by the sides AD and Dz ; therefore the angle DBx is equal to the angle DAz .

The angles DAB , and DBA , are equal, and subtracting their sum from 180 we have the angle ADB ; but the sum of the angles xBA , and zAB , is equal to the sum of the angles DAB , and DBA , for the angle DBx is added to the angle DBA , and the angle DAz (equal

to

to the angle DBx is subtracted from the angle DAB ; therefore, the angle ABx is equal to the angle ADB , and of consequence the arch of the circle will pass thro' both; the like may be said of all the rest.

Proportions for the length of Masts, Anna 1745.

			Guns
			100
			90
			80
1000 : breadth ::	748 :	main mast in yards	70 and 60
in feet	756 :		50
	753 :		44
	741 :		24
	740 :		
	747 :		
	760 :		
1000 : main mast ::	895 :	fore-mast	100 90 80
	901 :		all the rest
1000 : main mast ::	870 :	mizen-mast	100 90 80
	866 :		all the rest
1000 : main mast ::	640 :	bow-sprit	100 90 80
	613 :		all the rest
	600 :		100 90 80
1000 : main mast ::	605 :	main-top-mast	70 60 50 40
	607 :		24
1000 : main-top-mast ::	900 :	fore-top-mast	100 90 80
	910 :		all the rest
1000 : main-top-mast ::	710 :	mizen-top-mast	100 90 80
	717 :		all the rest
1000 : main-top-mast ::	480 :	main-top gallant	100 90 80
	508 :	mast	all the rest
1000 : fore top-mast ::	480 :	fore top-gallant	100 90 80
	505 :	mast	all the rest
1000 : bow-sprit ::	360 :	sprit-fail top-mast	100 90 80

Proportions for the length of yards.

			Guns
			100
			90 80
			70
			60
			50 24
			44
1000 : gun deck ::	560 :	main yard	
	559 :		
	570 :		
	576 :		
	575 :		
	561 :		
1000 : main yard ::	880 :	fore yard	100 90 80
	874 :		all the rest

1000.

1000 : main yard ::	$\left\{ \begin{array}{l} 820 : \\ 847 : \\ 840 : \end{array} \right\}$	mizen yard	$\left\{ \begin{array}{l} 100 \quad 98 \quad 80 \quad 60 \quad 44 \\ 70 \\ 24 \\ 24 \end{array} \right\}$
1000 : main yard ::	$\left\{ \begin{array}{l} 726 : \\ 720 : \end{array} \right\}$	main top sail yard	$\left\{ \begin{array}{l} 24 \\ \text{all the rest.} \end{array} \right\}$
1000 : fore yard ::	$\left\{ \begin{array}{l} 719 : \\ 726 : \\ 715 : \end{array} \right\}$	fore top-sail-yard	$\left\{ \begin{array}{l} 70 \\ 24 \\ \text{all the rest.} \end{array} \right\}$
1000 : main top sail ya. ::	690 :	maintop gall yard	all the rates
1000 : fore top-sail ya. ::	$\left\{ \begin{array}{l} 696 : \\ 690 : \end{array} \right\}$	fore top gal. ya.	$\left\{ \begin{array}{l} 70 \\ \text{all the rest.} \end{array} \right\}$
1000 : fore top-sail ya. ::	$\left\{ \begin{array}{l} 768 : \\ 750 : \end{array} \right\}$	miz. top-sail ya.	$\left\{ \begin{array}{l} 70 \\ \text{all the rest.} \end{array} \right\}$

Cross jack and sprit-sail yards equal to the fore top-sail yard.

Sprit top-sail yard equal to the fore top gallant yard.

Having now found the length of the masts and yards ; our next business is to determine their diameters at the partners and flings.

Proportions for the Diameters of Masts and Yards.

The main and fore mast in all ships down to 60 guns, 1 inch diameter to every yard in length.

For 50 and 40 guns, twenty-seven twenty-eighths of an inch diameter, to one yard in length.

For 24 guns, twelve thirteens of an inch diameter to one yard in length.

All top masts are nine tenths of an inch diameter to one yard in length.

The fore top-mast as big as the main top-mast.

The top gallant mast, one inch to a yard.

The mizen-mast $\frac{1}{4}$ of an inch to 1 yard in length.

The mizen top-mast five sixths of an inch to one yard in length.

The bow-sprit an inch and half to one yard.

The flying gibb-boom seven eighths of a ship to a yard.

The main and fore yard five sevenths of an inch to a yard.

The top-sail, cross-jack, and sprit-sail yards nine fourteenths of an inch to one yard.

The top-gallant, mizen top-sail, and sprit-sail top-sail yards eight thirteenths of an inch to one yard.

The

The mizen yard five ninths of an inch to one yard.
 All steering sail booms and yards half an inch to one yard in length.

Proportions for the diameters, at the quarters of masts and yards, according to their diameters at the partners, or slings.

For the main and fore mast, first quarter $\frac{1}{4}$ parts; second quarter $\frac{1}{4}$ parts; third quarter $\frac{1}{4}$ parts; hounds $\frac{1}{4}$ parts; for the head $\frac{1}{4}$ parts; heel $\frac{1}{4}$ parts.

For the mizen mast, and sloop's masts that head themselves, first quarter $\frac{1}{4}$; for the second quarter $\frac{1}{4}$; for the third quarter, a strait line from the second to the hounds; hounds three quarters; for the head two thirds.

For top and top gallant masts, first quarter $\frac{1}{4}$ parts; second quarter $\frac{1}{4}$ parts; third quarter $\frac{1}{4}$ parts; hounds $\frac{1}{4}$ parts; head $\frac{1}{4}$ parts.

For the bow-sprit, first quarter $\frac{1}{4}$ parts; second quarter $\frac{1}{4}$ parts; third quarter 3 quarters; at the cap one half; at the heel 3 quarters.

For yards in general; first quarter $\frac{1}{4}$ parts; second quarter nine tenths; third quarter seven tenths; yard arm two fifths.

For the lower arm of the mizen yard, first quarter $\frac{1}{4}$ parts; second quarter $\frac{1}{4}$ parts; third quarter $\frac{1}{4}$ parts; yard arm two thirds.

The upper arm of the mizen yard the same as yards in general.

As some of our readers may not be acquainted with the way of notation in these proportions, we refer them to what is said on that head in the first part, where the principles of the rule of proportion, and the construction of the line of numbers is explained, and the use of the sliding-rule illustrated by a great variety of examples in the rule of three.

Those that are but the least acquainted with the rule of three, know that there are three numbers given; and, that if the second be multiplied by the third, and that product divided by the first, the quotient will give the fourth term, which will have the same proportion to the third, that the second term has to the first.

The proportion for the main mast of a ship of 50 guns, is thus expressed; 1000 : 740 :: breadth : length, that is to say, (supposing the breadth be 41 feet): If 1000 give 740, what will 41 give?

Now, in order to give a solution to this by the sliding-rule, draw out the slider till 1000 is right against 740, and right against 41, you'll find 30 $\frac{1}{2}$ nearly, which is the length of the main-mast in yards: It is indif-

Supp.

P

ferent

ferent whether 1000 be on the slider or on the rule; but if 1000 be on the slider, 41 the breadth must likewise be on the slider, so 740 and $30\frac{1}{2}$, will be on the rule, and the contrary; or universally, the first and second terms will be on the same line of numbers, and the third and fourth on the other line of numbers, and it is indifferent whether 740, or the breadth, be the second term, but 1000 must be the first; and the length the fourth term; the one upon the slider and the other on the rule.

The diameter at the partners you will find in the proportions $\frac{1}{4}$ parts of an inch to every yard in length; that is to say, if the mast were 28 yards long, the diameter at the partners would be 27 inches; and therefore by the rule of three $28 : 27 :: 30\frac{1}{2} : 29\frac{1}{2}$; therefore, draw out the slider till 28 is against 27, and right against $30\frac{1}{2}$ is $29\frac{1}{2}$.

The diameters at the quarters are given in what the ship-wrights call fractional parts of the diameter at the partners, or slings; that of the first quarter of the main mast is $\frac{1}{4}$, that is to say, if the diameter at the partners be 43, that at the first quarter will be 42. Now the diameter at the partners, by the preceding operation, is $30\frac{1}{2}$, so we have three terms of the rule of three given, thus expressed, $43 : 42 : 30\frac{1}{2}$, and when the slider is drawn out till 43 is against 42, we shall find $29\frac{1}{2}$ against $30\frac{1}{2}$, so $29\frac{1}{2}$ inches is the diameter at the first quarter; hence we have this general rule; when the fractional part is given, draw out the slider till the denominator is right against the numerator, then look for the diameter at the partners, or slings, on the same line with the denominator; and right against the partners, or slings, you have the diameter for that quarter, and by using the same operation as for finding the first quarters, we shall find the second quarter $28\frac{1}{4}$; the third $25\frac{1}{4}$; the fourth $20\frac{1}{4}$; and at the head $17\frac{1}{4}$.

Now, to find the length and diameter of the main yard; the length of the gun deck is 144 feet, the proportion for the length is $1000 : 575 :: 144$, therefore, draw out the slider till 1000 is right against 575, and right against 144 is 83 nearly, which is the length of the main yard in feet.

The diameter at the slings is $\frac{1}{4}$ of an inch to every yard in length; 83 feet is $27\frac{1}{4}$ yards, therefore draw out the slider till 7 is against 5, and against $27\frac{1}{4}$ is $19\frac{1}{4}$.

It is presumed these examples may suffice to explain the manner of notation in the preceding proportions, and likewise the method of working by the sliding-rule, which may be applied to all questions in the rule of three, such as measuring plank, and timber, wainscoting, &c.

We

We shall now give our readers the proportions, for the heads, and hounds of masts, and likewise for the caps, tops, trussel-trees, and cross-trees.

Proportions for Heads and Hounds of Masts.

The head of the main and fore masts, five inches to one yard of the length of the mast.

Mizen-mast head, if it steps in the hold, $4\frac{1}{2}$ of an inch to one yard in length.

All top and top-gallant mast heads, four inches to a yard in length.

The length of the hounds, two fifths of their respective heads.

Proportions for Caps.

All caps, except the flying gibb boom, to be in breadth twice the diameter of their top-masts; and their lengths to be twice their breadth. The thickness of the main and fore caps, half the diameter of their breadths; the mizen cap three sevenths, and the top-masts two fifths of their respective breadths.

The flying gibb boom cap, to be in length five times the diameter of the boom, and in breadth twice its diameter, and, in depth, nine tenths of the breadth.

Proportions for Tops.

The breadth of the top thwartships, to be one third of the length of the top-mast; the mizen-top thwartships, by some, is nine thirtieths of the length of the mizen top-mast; all tops, before and aft, three fourths of what they are thwartships; the square hole five inches to a foot.

Proportions for Trussel-trees.

In length, to reach within three inches of the outer edge of the top.

The depth of the main and fore trussel-trees, $\frac{2}{3}$ of an inch to one foot in length; their breadth five sevenths of their depth.

The depth of the mizen trussel-trees, six sevenths of an inch to one foot in length; and their breadth eleven sixteenths of their depth.

The main and fore top-mast trussel-trees, to be in length the fifth part of the length of their top-gallant-masts; their depths $\frac{1}{4}$ of an inch to one foot in length, and their breadth $\frac{1}{3}$ of their depth.

The mizen-top-mast trussel-trees, half the length of the main-top-mast trussel-trees; their depth, one inch to a foot in length, and their breadth five sixths of their depth.

Pro-

Proportions for Cross-trees.

The length of the cross-trees, for the main and fore cross-trees, to reach within three inches of the outer edge of the top.

The mizen cross-trees, the same length with the trussel-trees.

The cross-trees the same breadth with the trussel-trees, and half their depth.

Weight of Anchors, and Dimensions of Cables.

In the merchant service, the sheet, best, and small bower anchors are generally different, but in the navy these three are of the same weight. The dimensions of the cables are estimated by their circumferences.

ANCHORS.	100 Guns. C. qrs.	90 Guns. C. qrs.	80 Guns. C. qrs.	74 Guns. C. qrs.	64 Guns. C. qrs.	50 Guns. C. qrs.	40 Guns. C. qrs.	32 Guns. C. qrs.	Sloops. C. qrs.
Bowers	77 0	71 2	66 2	71 2	54 2	44 0	37 3	32 0	15 0
Stream	19 2	17 0	15 2	13 1	13 0	11 0	10 2	8 1	7 0

CABLES.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
Sheet & bow.	23	22	21	22	18½	17½	16	14½	13
Stream	14½	13½	13	13½	11½	11	10	8½	8
Hawfers	9½	9	8½	9	8	7½	6½	5½	4½
ditto	9	8½	8	8½	7½	6½	6½	5½	4½

A TABLE of the Number of Guns on each Deck, their Length, Weight of Metal, and Shot.

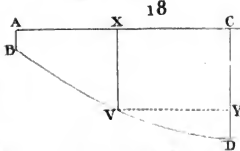
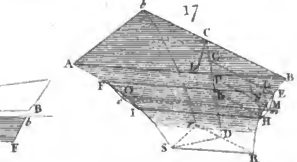
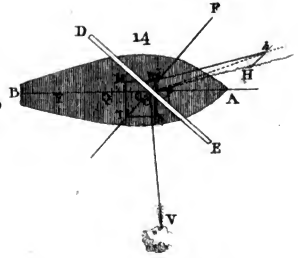
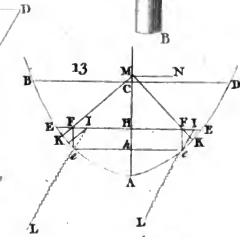
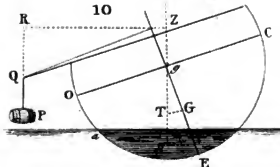
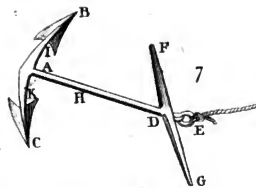
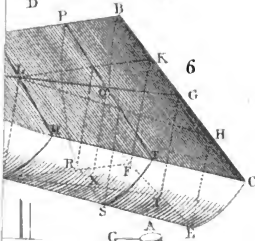
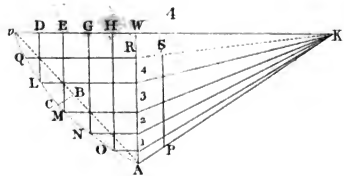
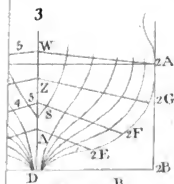
Guns	DECKS.	Number on each	Length feet in.	Wt. of metal. C wt.	Wt. of shot. pounds.
100.	Lower	28	10 0	67	42
	Middle	28	9 6	49	24
	Upper	28	9 6	34	12
	Quarter	12	8 0	22	6
	Fore Castle	4	9 0	24	6
90.	Lower	26	9 6	55	32
	Middle	26	9 6	42	18
	Upper	26	9 0	32	12
	Quarter	10	8 0	22	6
	Fore Castle	2	9 0	24	6

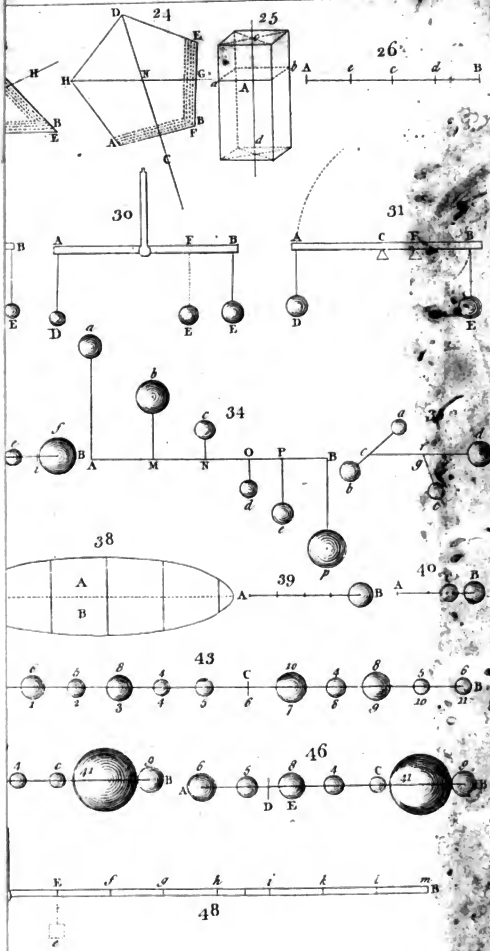
A TABLE

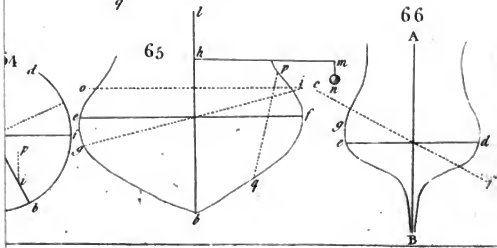
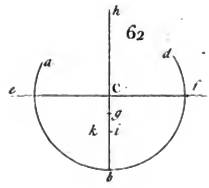
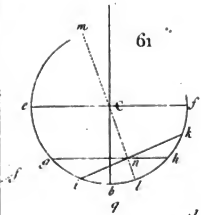
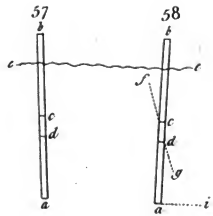
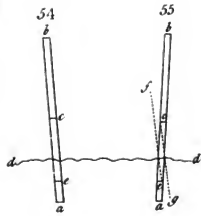
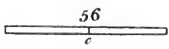
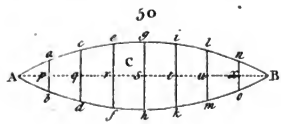
A TABLE of the Number of Guns on each Deck, their Length, Weight of Metal, and Sbst.

Guns	DECKS	Number on each	Length feet in.	Wt. of metal. C wt.	Wt. of shot. pounds.
80	Lower	26	9 6	55	32
	Middle	26	9 0	40	18
	Upper	24	9 0	29	9
	Quarter	4	7 6	20 $\frac{1}{2}$	6
74	Lower	28	9 6	55	32
	Upper	28	9 0	40	18
	Quarter	16	8 0	26 $\frac{1}{2}$	9
	Fore Castle	2	9 0	29	9
64	Lower	26	9 6	55	32
	Upper	26	9 0	40	18
	Quarter	10	7 6	24 $\frac{1}{2}$	9
	Fore Castle	2	8 6	27 $\frac{1}{2}$	9
60	Lower	24	9 6	49	24
	Upper	24	9 0	32 $\frac{1}{2}$	12
	Quarter	8	7 0	20 $\frac{1}{2}$	6
	Fore Castle	2	8 6	23	6
50	Lower	22	9 0	47 $\frac{1}{2}$	24
	Upper	22	8 6	31	12
	Quarter	4	7 8	18	6
	Fore Castle	2		22	6
44	Lower	20	9 0	40	18
	Upper	20	8 0	26	9
	Quarter	4	6 6	18	
24	Lower	2	7 0	23	9
	Upper	20	7 0	23	9
	Quarter	2	4 6	7 $\frac{1}{2}$	3

F I N I S.









$f_{1.5} 11''$

1871

BOOKS Printed for and Sold by A. MILLAR opposite Catherine-Street in the Strand.

A New System of Geography: In which is given a general Account of the Situation and Limits, the Manners, History, and Constitution of the several Kingdoms and Estates in the known World; and a very particular Description of their Subdivisions and Dependencies; their Cities and Towns, Ports, Sea-ports, Produce, Manufactures, and Commerce.

By *A. F. Buching*, D. D.

Carefully translated from the last Edition of the *German* Original. To the Author's Introductory Discourse are added three Essays, relative to the Subject. Illustrated with 36 Maps, accurately profected on a new Plan. This Work makes the best Geographical Dictionary extant, by a full and excellent Index now added. In 6 vols.

2. The Doctrine of Chances: Or, a Method of calculating the Probabilities of Events In Play. The third Edition, Fuller, Clearer, and more Correct than the former, being enlarged One Third more.

3. *Miscellanea Analytica de Seriebus et Quadraturis. Cum Supplementum.*
The above two by *Abraham de Moivre*.

4. An Account of Sir *Isaac Newton's* Philosophical Discoveries. In four Books. By *Colin Mac Laurin*, A. M. late Fellow of the Royal Society, Professor of Mathematicks in the University of *Edinburgh*, and secretary to the Philosophical Society there. Published from the Author's MSS Papers. To which is added, An Account of the Life and Writings of the Author. By *Patrick Murdoch*, M. A. and F. R. S.

5. *Geometria Organica: Sive Descriptio, Linearum Curvarum Universalis.* Auctore *Colino Mac Laurin*.

6. A Treatise of Fluxions. In two Books. By *Colin Mac Laurin*, A. M. Professor of Mathematicks in the University of *Edinburgh*, and late Fellow of the Royal Society. 2 vols.

7. *Mercator's* Sailing, applied to the true figure of the Earth. With an Introduction concerning the Discovery and Determination of that Figure. By *Patrick Murdoch*, A. M. Rector of *Stradshall* in *Suffolk*.

8. A New System of Arithmetick, Theoretical and Practical.

9. A Treatise of Book-keeping, or Merchant's Accounts; in the *Italian* Method of Debtor and Creditor.

10. Astronomy explained, upon Sir *Isaac Newton's* Principles, and made easy to those who have not studied Mathematicks. 3d Edition, with great Additions.

11. Lectures on several Subjects, in Mechanics, Hydrostaticks, Pneumaticks, and Opticks; with the Use of the Globes; the Art of Dialing, and the Calculation of the Mean Times of new and full Moons and Eclipses. The 2d Edition Corrected.

The above two by *James Ferguson*. F. R. S.

12. Some Observations made in travelling through *France, Italy, &c.* in the Years 1720, 1721, and 1722. 2d Edition. By *Edward Wright*, Esq; 2 vols.

13. *Maths*: Or, The *Cosmotheoria Puerrilis*. A Dialogue. In which the first Principles of Philosophy and Astronomy are accommodated to the Capacity of young Persons; or such as have yet no Tincture of these Sciences. Hence the Principles of Natural Religion are deduced. In 2 vols. The 2d Edition. To which is added, an Index.

15. A com-

BOOKS Printed for A. MILLAR.

14. A complete Treatise of Practical Navigation, demonstrated from its first Principles: Together with all the necessary Tables. To which are added, the use Theorems of Mensuration, Surveying, and Gauging; with their Application to Practice. By *Archibald Patoun*, F. R. S. The sixth Edition, with Additions.

15. The Figure of the Earth determined from Observations made by Order of the French King at the Polar Circle: By *Messieurs De Maupertuis, Camus, Clairaut, Le Monnier*, Members of the Royal Academy of Sciences; the *Abbe Oubier*, Correspondent of the Academy; and *M. Celsius*, Professor of Astronomy at *Upsal*. Translated from the French of *M. De Maupertuis*.

16. *Newtoni Genesis Curvarum per Umbrae. Seu Perspectivæ Universalis Elementa; Exemplis Coni Sectionum & Linearum Tertiæ Ordinis Illustrata.*

17. *Philosophiæ Moralis Institutio Compendiaria Libri III.* Ethices et Jurisprudentiæ Naturalis Elementa continens. Auctore *Francisco Hutcheson* in *Academia Glasguensi*, P. P. Editio altera auctor & emendatio.

18. A Treatise of Decimal Arithmetick; or, Decimals applied to the common Rules of Arithmetick. By *R. Gadsby*, Writing-Master and Accomptant.

19. A Treatise of Algebra. The 2d Edition.

20. An Account of Sir *Isaac Newton's* Philosophical Discoveries. In Four Books. Published from the Author's MSS Papers. To which is added, An Account of the Life and Writings of the Author. By *Patrick Murdoch*, M. A. and F. R. S. The 2d Edition.

The above two by *Colin Mac Laurin*, A. M.

21. *Euclid's* Elements of Geometry, from the Latin Translation of *Commandine*. The 7th Edition. By *Samuel Cunn*.

22. *Euclid's* Data restored to their True and Genuine Order, agreeable to *Pappus Alexandrinus's* Account of them, in his Preface to the seventh Book of his Mathematical Collections. By *Richard Jack*, Teacher of Mathematics.

23. Select Parts of Professor *Saunderson's* Elements of Algebra, for the use of Students at the Universities.

24. The Method of Fluxions, applied to a select Number of Useful Problems; Together with the Demonstration of Mr *Cote's* forms of Fluents, in the 2d Part of his *Logometria*; the *Analysis* of the Problems in his *Scholium Generale*: And an Explanation of the principal Proposition of Sir *Isaac Newton's* Philosophy. Illustrated with Copper-Plates. By *Nicholas Saunderson*, L. L. D. late Professor of Mathematics in the University of Cambridge. 2d Edition,

25. A Treatise, containing the practical Part of Fortification. In 4 Parts. Illustrated with 28 Copper-Plates. For the use of the Royal Academy of Artillery at *Woolwich*. By *John Muller*, Professor of Artillery and Fortification.

Henry Evans

This book should be returned to the Library on or before the last date stamped below.

A fine of five cents a day is incurred by retaining it beyond the specified time.

Please return promptly.

1970H
CANCELLED
317

~~APR 12 1944~~

~~APR 10 1951~~

FOR USE IN
BUILDING

1374902

3482
CANCELLED
JUL 31 71SS

Eng 8067.64
The elements(1) of na
Cabot Science



3 2044 092

